

## MEMOIRS OF THE GEOLOGICAL SURVEY.

## SCOTLAND.

THE GEOLOGY  
OF THE COUNTRY NEAR  
OBAN AND DALMALLY.  
(EXPLANATION OF SHEET 45.)

BY

H. KYNASTON, B.A., AND J. B. HILL, R.N.;

WITH CONTRIBUTIONS BY

B. N. PEACH, LL.D., F.R.S.; J. S. GRANT WILSON;

H. B. MUFF, B.A.; AND E. B. BAILEY, B.A.

WITH

PETROLOGICAL NOTES

BY

J. J. H. TEALL, D.Sc., F.R.S.; AND J. S. FLETT, M.A., D.Sc.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.



GLASGOW:

PRINTED FOR HIS MAJESTY'S STATIONERY OFFICE

By JAMES HEDDERWICK &amp; SONS LTD.

At "THE CITIZEN" PRESS, ST. VINCENT PLACE.

And to be purchased from

W. &amp; A. K. JOHNSTON, LTD., 2 ST. ANDREW SQUARE, EDINBURGH;

E. STANFORD, 12, 13, and 14 LONG ACRE, LONDON;

HODGES, FIGGIS &amp; CO., LTD., GRAFTON STREET, DUBLIN;

From any Agent for the sale of Ordnance Survey Maps; or through any  
Bookseller from the Ordnance Survey Office, Southampton.

1908.

*Price, Two Shillings and Sixpence.*



**Charles Seale-Hayne Library  
University of Plymouth**

**(01752) 588 588**

[LibraryandITenquiries@plymouth.ac.uk](mailto:LibraryandITenquiries@plymouth.ac.uk)

**WITHDRAWN  
FROM  
UNIVERSITY OF PLYMOUTH  
LIBRARY SERVICES**







MEMOIRS OF THE GEOLOGICAL SURVEY.

# SCOTLAND.

## THE GEOLOGY OF THE COUNTRY NEAR OBAN AND DALMALLY. (EXPLANATION OF SHEET 45.)

BY

H. KYNASTON, B.A., AND J. B. HILL, R.N.;

WITH CONTRIBUTIONS BY

B. N. PEACH, LL.D., F.R.S.; J. S. GRANT WILSON;

H. B. MUFF, B.A.; AND E. B. BAILEY, B.A.

WITH

PETROLOGICAL NOTES

BY

J. J. H. TEALL, D.Sc., F.R.S.; AND J. S. FLETT, M.A., D.Sc.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.



GLASGOW:

PRINTED FOR HIS MAJESTY'S STATIONERY OFFICE

By JAMES HEDDERWICK & SONS LTD.

At "THE CITIZEN" PRESS, ST. VINCENT PLACE.

And to be purchased from

W. & A. K. JOHNSTON, LTD., 2 ST. ANDREW SQUARE, EDINBURGH;

E. STANFORD, 12, 13, and 14 LONG ACRE, LONDON;

HODGES, FIGGIS & Co., LTD., GRAFTON STREET, DUBLIN;

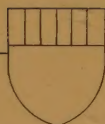
From any Agent for the sale of Ordnance Survey Maps; or through any  
Bookseller from the Ordnance Survey Office, Southampton.

1908.

*Price, Two Shillings and Sixpence.*



UNIVERSITY  
OF  
ABERDEEN



*Class Libraries*

Department of

*Purchased in 19.....*

*Shelfmark .....*



## PREFACE.

---

THIS Memoir describes the geology of the area included in Sheet 45 of the one-inch map of Scotland, which embraces the district on either side of Loch Awe near Kilchrenan, the tract between Oban and Dalmally, and the mountainous ground between Loch Creran and Glen Orchy. The prominent geological features of the region are (1) the development of various subdivisions of the metamorphic series of the Eastern Highlands and their associated igneous rocks, (2) the succession of contemporaneous lavas and tuffs that form the volcanic plateau of Lorne, (3) the large area of plutonic rocks that stretch from Ben Cruachan northwards to the margin of the map.

The central portion, comprising a broad belt crossing the sheet in a north-east and south-west direction, was mapped by Mr. Kynaston. It includes the region occupied by the plutonic masses north of Ben Cruachan, the eastern portion of the volcanic plateau of Lorne, and the metamorphic rocks on either side of Loch Awe near Kilchrenan, in the Pass of Brander, in the higher reaches of Glen Strae, and in Glen Orchy. Mr. Hill surveyed a tract extending from Glen Fyne north-westwards to Dalmally and also the lower portions of Glen Strae and Glen Orchy.

The western portion, from Loch Creran southwards across Benderloch, by Connel Ferry to Loch Scamadale, was mapped by the late Mr. Symes, and Dr. Peach revised a part of the volcanic plateau east of Kilmore. Mr. Wilson surveyed the area on the north side of Loch Creran, Mr. H. B. Muff the part of the island of Lismore included in the sheet, and Mr. Bailey revised the belt of low ground that stretches southwards to the headlands west of Ardmucknish Bay.

The Memoir has been mainly written by Mr. Kynaston and Mr. Hill, with contributions from Dr. Peach, Mr. Wilson, Mr. Muff, and Mr. Bailey.

The petrographical examination of the rocks has been done partly by Mr. Kynaston, Dr. Flett, and myself, and partly by Mr. Hill and Mr. Bailey.



Mr. E. T. Newton, F.R.S., determined the fossils from the shelly marine clays on the south shore of Loch Creran and furnished the list given in the Memoir.

The list of publications referring to the geology and mineralogy of the district has been prepared by Mr. Tait.

The photographs reproduced in Plates I. to III. and V. to VII. inclusive have been taken by Mr. Lunn and those in Plate IV. by Dr. Flett.

The Memoir has been edited by Dr. Horne.

J. J. H. TEALL,  
*Director.*

GEOLOGICAL SURVEY OFFICE,  
22 JERMYN STREET,  
LONDON, *February 27th, 1908.*

| PLYMOUTH POLYTECHNIC<br>LIBRARY |              |
|---------------------------------|--------------|
| Accn.<br>No.                    | 186740-8     |
| Class<br>No.                    | 554.1423 KYN |
| Contl.<br>No.                   | X700299318   |

# CONTENTS.

|                                                                          | PAGE |
|--------------------------------------------------------------------------|------|
| CHAPTER I.                                                               |      |
| Area and Physical Features, . . . . .                                    | 1    |
| CHAPTER II.                                                              |      |
| Formations and Groups of Rock—Distribution of Rock Formations, . . . . . | 6    |
| CHAPTER III.                                                             |      |
| Metamorphic Rocks—                                                       |      |
| i. Schists in south-east corner of map, . . . . .                        | 10   |
| ii. Green Beds, . . . . .                                                | 12   |
| iii. Loch Tay Limestone, . . . . .                                       | 14   |
| iv. Garnetiferous Mica-Schist, . . . . .                                 | 15   |
| CHAPTER IV.                                                              |      |
| Metamorphic Rocks ( <i>continued</i> )—                                  |      |
| v. Ardrishaig Phyllites, . . . . .                                       | 19   |
| vi. Loch Awe Group, . . . . .                                            | 23   |
| vii. Granulitic Schists of the Moine type, . . . . .                     | 38   |
| CHAPTER V.                                                               |      |
| Older Igneous Rocks—                                                     |      |
| i. Epidiorites and Hornblende-Schist, . . . . .                          | 41   |
| ii. Contact-Metamorphism produced by Older Basic<br>Masses, . . . . .    | 45   |
| CHAPTER VI.                                                              |      |
| Folded and Regional Metamorphism, . . . . .                              | 47   |
| CHAPTER VII.                                                             |      |
| Old Red Sandstone, . . . . .                                             | 62   |
| CHAPTER VIII.                                                            |      |
| Newer Igneous Rocks, . . . . .                                           | 82   |
| CHAPTER IX.                                                              |      |
| Sills and Dykes, . . . . .                                               | 111  |
| CHAPTER X.                                                               |      |
| Contact-Metamorphism produced by the Newer Igneous Masses, . . . . .     | 139  |



|                                        | PAGE |
|----------------------------------------|------|
| CHAPTER XI.                            |      |
| Carboniferous Formation, . . . . .     | 154  |
| CHAPTER XII.                           |      |
| Faults, . . . . .                      | 156  |
| CHAPTER XIII.                          |      |
| Glacial and Recent Deposits, . . . . . | 159  |
| CHAPTER XIV.                           |      |
| Economic Geology, . . . . .            | 173  |
| APPENDIX.                              |      |
| Bibliography, . . . . .                | 175  |

## LIST OF ILLUSTRATIONS.

### FIGURES IN TEXT.

|                                                                                                   |     |
|---------------------------------------------------------------------------------------------------|-----|
| FIG. 1. Section from Oban across the volcanic plateau to Kilbride Burn, . . . . .                 | 71  |
| „ 2. Composite Dyke exposed on south shore of Loch Fiochan, four miles south from Oban, . . . . . | 135 |

### PLATES.

|                                                                                                                             |                 |
|-----------------------------------------------------------------------------------------------------------------------------|-----------------|
| PLATE I. The Pass of Brander, . . . . .                                                                                     | Frontispiece.   |
| „ II. Boulder Bed, shore of Loch Awe, near Manse, Kilchrenan, . . . . .                                                     | to face page 30 |
| „ III. Altered and Folded Limestone, Barr Dubh, a quarter of a mile east of Socach, three miles east of Dalmally, . . . . . | to face page 53 |
| „ IV. Crush Conglomerate, on shore Port Selma, three hundred yards west of Benderloch Railway Station, . . . . .            | to face page 59 |
| „ V. Coire Creachainn in Granite, east side of Ben Cruachan, $3\frac{1}{2}$ miles W.N.W. of Dalmally, . . . . .             | to face page 82 |
| „ VI. Boulder of Kentallenite, $\frac{1}{3}$ -mile west of Kilchrenan, . . . . .                                            | to face page 92 |
| * „ VII. Aplite Veins in Granite, Ben Cruachan Granite Quarries, three miles W.N.W. of Dalmally, . . . . .                  | 173             |

# EXPLANATION OF SHEET 45.

---

## CHAPTER I.

### AREA AND PHYSICAL FEATURES.

*Area.*—The district represented in Sheet 45 of the Geological Survey Map of Scotland is situated almost wholly in the county of Argyll, and embraces an area of 416 square miles. The northern boundary of the sheet extends from the north-east end of Lismore, eastwards across Glen Creran and Glen Etive to the eastern portion of the Blackmount Deer Forest. On the south, the margin of the map extends from the high road through Glen Gallain, two miles south-west of Loch Scamadale, across Loch Awe to the upper part of Glen Fyne. Oban is the only town of any importance on the map, and is situated on its western margin, while the central portion is occupied by Ben Cruachan and the mountainous ground lying between Loch Etive and Glen Strae.

The Callander and Oban branch of the Caledonian Railway enters the eastern portion of the map in Glen Lochy, and passes through Dalmally and the Pass of Brander to Taynuilt, whence it follows the southern shore of Loch Etive to Connel Ferry and Oban. The principal high road on the map follows the course of the railway, while other high roads run from Dalmally along the south-east side of Loch Awe, branching southward at Cladich for Inveraray; from Taynuilt to Kilchrenan; from Oban southwards past Kilmore, being the road to Kilmelfort and Ardrishaig; and from North Connel Ferry in a northerly direction to communicate with the district about Loch Creran and Appin.

*Physical Features.*—The most elevated area on the map occupies nearly the whole of its northern half, and is sharply defined from the comparatively low ground to the south-west by the well-marked line of feature coinciding with the Pass of Brander and Glen Salach. The most conspicuous and commanding feature of this mountainous region is the imposing granite mass of Ben Cruachan, which forms a well-marked east and west ridge, culminating towards its central portion in two sharp peaks, the highest of which rises to 3689 feet above sea-level. The western slopes of Ben Cruachan stretch down to the banks of the river Awe at Bonawe. To the south it directly overlooks the Pass of Brander, and extends eastwards in diverging ridges and spurs as far as the head of Loch Awe. On the north-east side of Ben Cruachan a succession of deep glens, separated by mountain groups, forms a wild and some-

what inaccessible country as far as the northern margin of the map. In this area no less than eight mountains rise to over 3000 feet above sea-level, the most elevated group being situated to the north of Glen Kinglass, and constituting a large portion of the Blackmount Deer Forest. On the west side of Loch Etive a rugged group of granite hills, rising to over 3000 feet in Beinn Sguliaird, forms the watershed between Loch Etive and Loch Creran.

To the east of the great granitic mass of Ben Cruachan and the Blackmount, the hills are of more rounded form and smoother outline, and seldom rise above 2500 feet. Further south the metamorphic area to the east of Loch Awe rises gradually towards Beinn Bhalgairean, 2085 feet, and reaches its greatest elevation in Beinn Laoigh, on the Perthshire boundary, and just outside the eastern margin of the map. Further south another elevated area is situated between Glen Shira and Glen Fyne, the highest point being Beinn Bhuidhe, 3106 feet.

The greater part of the western portion of the map consists of comparatively low ground, the highest hill in the Lorne volcanic area being Beinn Ghlas, 1691 feet above sea-level, and situated near the central portion of that area. The scenery of this region is characteristic and entirely dependent upon the geological structure, the forms of the hills and lines of crag and escarpment being directly due to the character and mode of behaviour of the lava-flows or masses of fragmental volcanic rock of which they are composed. The glens of this region are comparatively small and narrow, though frequently deep and bounded by steep craggy slopes. To the west of the volcanic area of Benderloch, the harder bands of the metamorphic series stand out as well-marked ridges, running north-east and south-west, above low ground for the most part covered by peat-mosses and deposits of the raised beaches, which prior to the elevation of the country must have formed an archipelago of rocky islets. Wherever we leave the volcanic plateau the form of the ground changes according to the character of the rocks beneath. The epidiorites form the rugged hills and elongated ridges about Loch Awe, sharp lines of ridge being also occasionally formed by the later porphyrite sills. The quartzites stand out, where well developed, in bold lines of crag, while the limestone usually forms smooth grass-covered slopes, and the black schists and phyllites occupy the hollows. The higher ground and bolder aspect of the hills to the east and north-east of Loch Awe is directly connected with the more highly metamorphosed condition of the rocks composing this area.

*Lakes and River Systems.*—The area included in the present map, comprising as it does some of the most typical aspects of West Highland scenery, is not lacking in both the fresh and salt-water lochs which give that scenery perhaps its greatest charm. The long, narrow, fjord-like sea-lochs of the West Highlands are here typically represented by Loch Etive. A few miles north of Oban this loch runs inland in an easterly direction for eight miles; it then bends round to the north-east and stretches away for over



ten miles almost to the northern edge of the map. The principal rivers which drain into Loch Etive are the river Awe, entering at Bonawe, the river Etive at the head of the loch, and the river Kinglass, about halfway between the two, and on the east side of the loch. The Kinglass drains a large portion of the granite area of the Blackmount, and rises in the high ground E.S.E. of Beinn Starav. The river Awe flows from Loch Awe through the remarkable gorge known as the Pass of Brander. This gorge corresponds with a line of fault extending from Glen Salach on the north-west to Loch Awe. It is owing to the gradual excavation of this feature that the waters of Loch Awe are now drained by the river Awe, instead, as one would expect, of finding their way out at the south-west end of the loch. That the loch was formerly at a considerably higher level, and drained out at the south-west end, may be proved by the occurrence of the old loch-beaches, seen at various places along its shores, and especially well developed in the neighbourhood of Ford at the far end, and there is strong evidence of the existence of the ancient waterway between Ford and Kilmartin by which the loch was at one time drained. This point is referred to in the Explanation of Sheet 37.

At its north-east end Loch Awe is fed by the waters of the river Strae and the Orchy. The Strae rises among the quartzose flagstone hills on the north side of Beinn Mhic-Mhonaidh, and has a straight south-westerly course, which coincides with a well-marked line of fault crossing the southern portion of the Blackmount and the Moor of Rannoch to the north-east. About nine miles of the river Orchy are seen on the map, with about four miles of the river Lochy, its principal tributary, which enters it a mile and a half above Dalmally. Up to the junction of the Lochy the Orchy has a westerly course, above which it runs parallel to the river Strae. The two principal streams which flow into the east side of Loch Awe, namely, the Cladich river and the Teatle Water, have a general westerly course, and drain the metamorphic area between Loch Awe and the watershed dividing it from Glen Shira and Glen Fyne.

In the eastern portion of the Lorne volcanic area the streams flow off the high ground near the central part of the area, on the one hand northwards to Loch Etive, and on the other hand south-eastwards to Loch Awe. On the west side they have for the most part a general westerly direction towards the sea-lochs situated to the south of Oban. The whole area is dotted here and there by lochs and small lochans, the two largest being Loch Nell and Loch Scamadale. The Black Lochs form a chain of small lakes lying north-east and south-west, and situated about two miles south-east of Connel Ferry. These lochs drain into Loch Etive by a stream which flows out at their south-west end and curves round till it takes a northerly course to Connel Ferry. It would seem probable, however, that we may have here also a reversal of the original state of things, owing to the blocking up of the north-east end of the lochs by glacial accumulations. Numerous small lochs occupy small basins in the metamorphic rocks in the area about Kil-



chrenan. The chief of these are Loch Nant, which drains to the north into Glen Nant and so into Loch Etive, and Loch an Leòid and Loch an Droighinn, discharging eastwards into the Kilchrenan burn, which flows southwards into Loch Awe. Many of the smaller lochans among the hills are now partially silted up by the accumulations of peat-forming plants, and the peat-covered sites of previous lochans are frequently met with in the hollows among the hills.

In the north-western corner of the map we see the whole of Loch Creran, one of the shorter and less important of the sea-lochs, with its somewhat sinuous form, entering Loch Linnhe opposite the north-eastern end of Lismore, and contributing to the remarkably irregular outline of that portion of the sea-coast.

*Population, etc.*—The distribution of the population over this area has to a large extent been determined by its geological structure, and the natural conditions coincident with a wet climate and large areas of elevated ground. Nearly all the land in this region, situated above 1000 feet, is destitute of population and given up to deer-forests or sheep-grazing. The population of so mountainous a region is of necessity, therefore, scanty and scattered, and mainly confined to the glens and the low-lying ground situated along the shores of the lochs. The most populous area is undoubtedly to be found in the western portion of the sheet, in the district about Oban, and in the low-lying portions of western Benderloch and Appin to the north. Further east, the shores of Loch Etive as far as Bonawe and Taynuilt support a moderate population, engaged in sheep-farming, cattle-rearing, agriculture, and local industries. The volcanic rocks which cover this area form a somewhat stony soil, but often fairly well adapted for arable purposes, and good for pasture. Considerable tracts on the south side of Loch Etive are covered by natural wood of birch and hazel, and in some places the landowners have raised plantations of coniferous trees, which are doing well. The higher ground between Loch Etive and Loch Awe is well adapted for heather, and is given up to grouse-moors and sheep-grazing.

The mountainous area to the north-east is divided into large sheep-farms as far as Glen Kinglass. The soil is poor and the ground is mainly covered by coarse grass. To the north of Glen Kinglass the granite is richer in quartz, and the lower slopes of the hills are often covered by short heather. All this portion of the area, together with a large part of the metamorphic area to the east, is deer-forest ground.

The district of Loch Awe-side and the Strath of Orchy is well adapted for supporting a rural population, and is peopled by numerous small farmers, shepherds, gamekeepers, etc. A good deal of the low ground is covered by drift, which, together with the alluvial ground, supports a good arable soil, well suited for crops or hay growing. Nearly the whole area to the east of Loch Awe consists of large sheep farms and grouse-moors, a part of the more elevated portion between Glen Shira and Glen Fyne being deer-forest. Towards the upper reaches of the glens the population

invariably becomes very scanty, the only dwellings being those of shepherds or gamekeepers, often situated at long distances from one another. Formerly, however, the whole of this area was far more thickly populated, chiefly by the crofter class, than at present, the numerous ruined buildings and patches of plough-marked ground affording abundant evidence of abandoned homesteads and deserted lands.

H. K.

## CHAPTER II.

### FORMATIONS AND GROUPS OF ROCK.

Before entering upon a geological description of the area, it will be convenient here to state in a tabular form the various formations and groups of rock which are included in the present sheet.

|                             |   |  |  |  |  |  |  |  |  |  |                                                                                                                    |                                                                                    |
|-----------------------------|---|--|--|--|--|--|--|--|--|--|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Glacial and Recent.         | { |  |  |  |  |  |  |  |  |  | Peat . . . . .                                                                                                     |   |
|                             | { |  |  |  |  |  |  |  |  |  | River and lake alluvium . . . . .                                                                                  |   |
|                             | { |  |  |  |  |  |  |  |  |  | Recent marine muds and sands . . . . .                                                                             |   |
|                             | { |  |  |  |  |  |  |  |  |  | Raised beaches . . . . .                                                                                           |   |
|                             | { |  |  |  |  |  |  |  |  |  | Erratic blocks . . . . .                                                                                           |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | Sands and gravels . . . . .                                                                                        |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | Moraines . . . . .                                                                                                 |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | Boulder clay . . . . .                                                                                             |                                                                                    |
| Highland Metamorphic Rocks. | { |  |  |  |  |  |  |  |  |  | Glacial striæ . . . . .                                                                                            |  |
|                             | { |  |  |  |  |  |  |  |  |  | Carboniferous.                                                                                                     |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | {                                                                                                                  |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | Sandstones and shales of the                                                                                       |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | Bridge of Awe . . . . .                                                                                            | d                                                                                  |
|                             | { |  |  |  |  |  |  |  |  |  |                                                                                                                    |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  |                                                                                                                    |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  |                                                                                                                    |                                                                                    |
| Highland Metamorphic Rocks. | { |  |  |  |  |  |  |  |  |  | Old Red Sandstone.                                                                                                 |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | {                                                                                                                  |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | Lower.                                                                                                             |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | {                                                                                                                  |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  | Conglomerates, sandstones, and shales, associated with the volcanic series . . . . .                               | c <sup>1</sup>                                                                     |
|                             | { |  |  |  |  |  |  |  |  |  |                                                                                                                    |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  |                                                                                                                    |                                                                                    |
|                             | { |  |  |  |  |  |  |  |  |  |                                                                                                                    |                                                                                    |
| Highland Metamorphic Rocks. | { |  |  |  |  |  |  |  |  |  | Albite schist . . . . .                                                                                            | la                                                                                 |
|                             | { |  |  |  |  |  |  |  |  |  | Garnetiferous mica-schists . . . . .                                                                               | g                                                                                  |
|                             | { |  |  |  |  |  |  |  |  |  | "Green Beds" . . . . .                                                                                             | p                                                                                  |
|                             | { |  |  |  |  |  |  |  |  |  | Clay slates, phyllites, and calc-sericite schists with thin limestones and quartzites (Ardrihaig series) . . . . . | l                                                                                  |
|                             | { |  |  |  |  |  |  |  |  |  | Black slates and schists . . . . .                                                                                 | li                                                                                 |
|                             | { |  |  |  |  |  |  |  |  |  | Quartzites and schistose grits . . . . .                                                                           | x                                                                                  |
|                             | { |  |  |  |  |  |  |  |  |  | Pebbly Limestone . . . . .                                                                                         | λ                                                                                  |
|                             | { |  |  |  |  |  |  |  |  |  | Granulitic schists of Moine type, with both muscovite and biotite . . . . .                                        | m                                                                                  |

| A.—CONTEMPORANEOUS. |                                                                 |                                                              |                  |
|---------------------|-----------------------------------------------------------------|--------------------------------------------------------------|------------------|
| Igneous Rocks.      | Of Lower Old<br>Red Sandstone<br>Age.                           | Andesites . . . . .                                          | Poc <sup>1</sup> |
|                     |                                                                 | Rhyolitic felsites . . . . .                                 | Fc <sup>1</sup>  |
|                     |                                                                 | Agglomerates and tuffs . . . . .                             | Tsc <sup>1</sup> |
|                     | B.—INTRUSIVE.                                                   |                                                              |                  |
|                     | <i>Post-foliation.</i>                                          |                                                              |                  |
|                     | Tertiary.                                                       | Dolerites and basalts . . . . .                              | B                |
|                     |                                                                 | Trachytes . . . . .                                          | Tr               |
|                     |                                                                 | Acid dykes (?) rhyolites . . . . .                           | F                |
|                     |                                                                 | Volcanic vents . . . . .                                     | Ni               |
|                     | Lower Old<br>Red Sandstone.                                     | Volcanic vents . . . . .                                     | Nc <sup>1</sup>  |
|                     |                                                                 | East and west dolerite dykes . . . . .                       | B                |
|                     |                                                                 | Granite . . . . .                                            | G                |
|                     |                                                                 | Diorite . . . . .                                            | D                |
|                     |                                                                 | Kentallenite . . . . .                                       | K                |
|                     |                                                                 | Porphyrite and andesite . . . . .                            | Po               |
|                     |                                                                 | Quartz-porphry, felspar-por-<br>phyry, and felsite . . . . . | F                |
|                     |                                                                 | Lamprophyre . . . . .                                        | S <sup>M</sup>   |
|                     | <i>Pre-foliation.</i>                                           |                                                              |                  |
|                     | Epidiorite, chlorite-schist, and<br>hornblende-schist . . . . . |                                                              | Bg               |

*Distribution and Development of the various Rock Formations and Groups.*—The area represented on the map may perhaps be said to be almost equally divided between the metamorphic rocks, the Lower Old Red Sandstone lavas, and the Ben Cruachan granite. On first glancing at the map, the eye is immediately arrested by the great mass of granite which occupies all the mountainous ground north-east of the Pass of Brander, and on both sides of Loch Etive above Bonawe Ferry. This mass comprises the well-known granite of Ben Cruachan and Bonawe, and an inner, more acid, and slightly younger granite which forms the wild hills on both sides of the upper portion of Loch Etive. Some subordinate intrusions of granite and diorite are seen in the north-east corner of the map, and the south-east corner includes a portion of the granite of Glen Fyne.

The line of fault which coincides with the remarkable feature of the Pass of Brander (Plate I., frontispiece) and with Glen Salach separates the granitic area of Ben Cruachan from the volcanic area of south-western Lorne. Thus by far the greater portion of the ground lying to the south-west of the Pass of Brander and Glen Salach is occupied by the andesitic and felsitic lava-flows, with their



associated tuffs and agglomerates, of the Lower Old Red Sandstone volcanic series.

A well-marked zone of hornfels accompanies the granite margin from the head of Loch Awe, forms the steep slopes on the north-east side of the Pass of Brander, thence follows the granite in a northerly direction towards Loch Creran, and forms the hill slopes to the south-east and east of the head of that loch.

The rest of the map is occupied by the metamorphic group and associated igneous rocks, with numerous small intrusions, mainly in the form of dykes, belonging to the later igneous series. The south-western portion of the mountainous area, stretching from the Strath of Orchy to the north-east corner of the map, consists to a large extent of massive quartzite, often pebbly, while the north-eastern portion is chiefly composed of granulitic schists of Moine type, together with a zone of flaggy quartzite, and another zone of garnetiferous mica-schist. The area about Loch Awe and between Loch Awe and Glen Fyne exhibits an interesting variety of rock type, structure, and metamorphism. It comprises the entire metamorphic series from the Loch Tay limestone, green beds, and albite schists of Glen Fyne up to a massive quartzite, which is frequently pebbly (Schiehallion). The phyllites of Ardrishaig type have the larger share of this ground. Striking north-east in a broad belt from Glen Shira, they spread out over the hills south-east of Dalmally and sweep round westwards to the head of Loch Awe. To the east of Dalmally they thin out into a comparatively narrow belt, rich in calcareous bands, and run eastwards into Perthshire. The black schists and limestone (of Loch Awe type) are perhaps best seen in the area about Kilchrenan, on the north-west side of Loch Awe. The limestone is again well developed in Lismore, in the north-west corner of the map, and forms a well-defined belt on the west side of Glen Creran.

The quartzite and schistose grits are well seen on the south-east side of Loch Awe, between Bovay and Glen Shira. The boulder bed is also seen at two or three places near the south-east shore of the loch, but the best exposures are to the west of Kilchrenan.

The igneous rocks of pre-foliation age are seen at a glance to reach their maximum development about Loch Awe, and here also, as will be seen in the following pages, they show their greatest diversity of composition and structure. The intrusions of epidiorite and hornblende schist evidently die out to the east and north-east of the Loch Awe area.

The distribution of the later dykes of porphyrite and quartz-porphry shows the remarkable development of these intrusives as a broad belt extending from the south-west corner of the map to Ben Cruachan, while they tend to die out on either side of this belt. To the east of Loch Awe the predominant type of later dyke is lamprophyre, this type being very common about Glen Shira.

The Tertiary dykes are almost entirely confined to the south-west of a line drawn from Oban to Inverinan on Loch Awe, and they are exceedingly numerous in the area about Loch Scamadale.

Superficial deposits do not occupy any very considerable areas

upon the map. The alluvial flats and terraces and the raised beaches are of small extent owing to the mountainous nature of the country and the consequent steep slopes of the glens. There are no large peat-mosses, with the exception, perhaps, of that on the north side of Connel Ferry. The hill peat nowhere covers large areas, but is scattered in patches chiefly over the volcanic area.

The low ground about Strath Orchy is extensively covered by a magnificent series of moraines, amid which the railway threads its course at Dalmally.

The present map shows a diversity of rock type and structure, combined with a variety of scenic feature, which is seldom seen in any other area of equal extent. There is thus not only a great variety of schistose rocks and metamorphic phenomena, but a very extensive development of igneous intrusions and lava-flows. So varied an area can hardly fail to constitute a wide field of geological interest and inquiry, and to afford the materials of problems, metamorphic and igneous, structural and physical, of which we will now proceed to give some account in the following chapters.

H. K.

## CHAPTER III.

### METAMORPHIC ROCKS.

#### i. SCHISTS SOUTH OF GREEN BEDS IN SOUTH-EAST CORNER OF SHEET.

1. *Lithological Characters*.—This small area is made up of the north-easterly prolongation of a group of rocks which have a wide extension in Cowal, and have been described in the Explanation of Sheet 37 as the Ben Bheula group. They consist of a series of gneissose grits and granulitic gneisses showing a high degree of metamorphism. While in mass they retain sufficient traces of their sedimentary character to leave little doubt of their origin, in individual rock fragments these indications are seldom so apparent.

In this area their deformation and mineral reconstruction have been so complete that the original clastic character has often been entirely destroyed. They consist essentially of a granulitic admixture of quartz and felspar lying between folia of sericitic mica and biotite. Chlorite, iron ores, and carbonates form the accessory minerals, while albite, andalusite, and actinolite are of more exceptional occurrence. The remains of clastic grains of quartz and felspar are represented by phacoids, which merge into the granulitic matrix, thus obliterating the boundaries of the larger clastic fragments, so that the outlines of the pebble-like grains are much less marked under the microscope. The quartz phacoids, however, often break up into a mosaic coarser than the matrix of the rock. The quartz phacoids are white and blue, the latter being sometimes slightly opalescent. The felspar phacoids are pink and white, the latter being predominant. The clastic grains have been drawn out and frequently fractured, and although the feldspars have more successfully resisted deformation than the quartz fragments, their stretching has sometimes been accompanied by fractures, the cracks being now infilled by secondary quartz. Moreover, the lenticles of quartz and felspar are bounded by tails of granulitised material.

The felspar of these gneisses is almost entirely plagioclase, but some untwinned felspar is occasionally seen, and no doubt orthoclase entered to a slight extent into their original composition. In this area the nature of the plagioclase has not been determined, but, judging from the extension of this group in adjoining districts, it is probable that it is largely restricted to oligoclase. The mica is mainly confined to the planes of foliation, but biotite also frequently occurs scattered broadcast through the rock.

These rocks present every gradation in texture from fairly

coarse-grained gneissose grits to highly micaceous schists, the latter, however, having been evolved from fine sandy shales rather than purely argillaceous beds. In this district the more siliceous types distinctly predominate. Moreover, the close interbanding of beds of divergent texture and composition as the result of uneven sedimentation reveals their aqueous origin in the finer and more compact schists, where no clastic fragments are preserved.

An important feature in this group of rocks is the occurrence of secondary albite in tiny crystals, which have been produced subsequent to foliation. The albite grains are of a dull brown colour, and contain numerous inclusions. They sometimes are so abundant as to form distinct zones of albite-bearing rock, but there is every gradation in their relative abundance. In the more chloritic and micaceous zones this mineral is most strongly developed, and is of rare occurrence in the more siliceous members.

In all the schists of this group the segregation of quartz, and to a smaller extent of felspar, has been considerable, so that veins of quartz and occasionally of pegmatite are commonly distributed, many of which have been formed prior to the period of rock deformation.

2. *Distribution and Field Relations.*—This group occupies an area of less than a square mile as an irregular strip of a north-north-east trend along the valley of the Fyne in the neighbourhood of Inverchorachan. To the east this band abuts against the Glen Fyne granite, the intrusion of that mass having determined the irregularity of its boundary. It lies between that granite and the Green Bed group, with which it forms a junction remarkably even. Situated within the granite aureole, it is not only frequently veined by granite, but has been subjected to contact action in addition to the regional metamorphism of the district, the effects of which are more particularly described in Chapter X. as regards the former, and in Chapter VI. as regards the latter.

In the hollow at An Caorachan there is a small intrusion of granite and two felsite dykes, which, together with the smaller granite veins, are the only igneous rocks contained within the group.

The schists of this area are of the siliceous type, and massive, but their dominant characteristic in the field is their highly contorted and gnarled structure, which has given rise to rugged features that form precipitous slopes which extend from the bed of the River Fyne. On the east side of that river they form a hillside over a thousand feet in height, with a breadth of only a quarter of a mile. They attain a like altitude on the western side, but the lower slopes are there largely occupied by granite. In this latter area andalusite is in many places very abundant, and blades of actinolite are frequently seen. Owing to the contortion the dip varies considerably, but notwithstanding the disturbing element of the granite mass in the immediate vicinity, there is a general north-westerly hade, in spite of occasional reversals. In an area, how-



ever, so intensely folded, the dips are of no stratigraphical importance, but merely indicate the inclination of the folded limbs.

The only fault of importance runs along the bed of Glen Fyne as far as Inverchorachan in a S.S.W. direction, and on the deflection of the River Fyne at that point it pursues its even course by ascending the hillside of An Caorachan. This line of fracture has there diverted the drainage of the upper slopes, which has excavated a deep hollow along the Allt a' Chaorachain burn. This fault, which extends from Perthshire to Loch Fyne, is in this area closely restricted to the junction of this group with the green beds, and may possibly account for the even nature of that junction south-south-west of Inverchorachan, where a rise of 800 feet from the bottom of the valley has not diverted the boundary. Minor faults parallel with and probably related to this fault occasionally give rise to straight features.

## ii. THE GREEN BEDS.

1. *Lithological Characters*.—The schistose grits, granulitic gneisses, and mica schists just described are succeeded to the north-west by schists of corresponding lithological character, but which contain in addition certain bands of epidotic, chloritic, and hornblendic schists that are known in the Highland sequence as Green Beds. In areas where regional metamorphism has not proceeded so far, the clastic origin of the Green Beds has been indubitably established. In the district, however, under description regional metamorphism is of such an advanced type that, as already described, the original clastic structures have often been completely obliterated, and sediments have been converted into holocrystalline rocks. The Green Beds in this area have suffered similar deformation and reconstruction, and are for the most part represented by hornblendic schists that are practically indistinguishable as regards their structure from igneous rocks.

The Green Beds, from their basic composition, differ so markedly from normal sediments that their inclusion among the former is a problem not easy to solve. While it is possible that they originated as volcanic ash, which was deposited on the sea floor during the accumulation of the normal sedimentary deposits, the absence of volcanic lapilli throws doubt on this hypothesis. Moreover, the igneous rocks on their horizon appear to belong to the intrusive group, and so far as the evidence goes volcanic rocks are absent in the area. It is possible, however, that the Green Beds, in common with the associated schists, were derived from the disintegration of an igneous complex, the more basic portion of which has furnished the materials for this abnormal deposit. The Green Beds are not sharply defined from the associated schists, but on the other hand the two types blend imperceptibly into one another, so that with the gradual diminution of the basic minerals the peculiar characteristics as gradually diminish; in such cases the demarcation of the Green Bed type is necessarily an arbitrary

distinction. In this area these rocks are very finely foliated, and the hornblende is practically confined to actinolite, so that they appear in the field as green and dark, finely-linear schists. Besides actinolite they contain chlorite, epidote, biotite, feldspar, quartz, iron ores, and occasionally tourmaline, but these minerals are not always present together. The feldspars are albite and oligoclase (acid plagioclase). The albite is usually present in small rounded crystals. It is never idiomorphic, and is a secondary mineral similar to that which enters into the composition of the albite schists, where it plays the same rôle as the garnets do in the garnetiferous mica schist group. Biotite is frequently an important constituent, but is more plentiful in association with chlorite than with hornblende. The occurrence of tourmaline in these rocks is peculiar, and that mineral appears to be confined to the hornblendic varieties. The Green Beds in this area differ from the epidiorites in the persistence of a more or less uniform structure. Whereas the hornblende of the epidiorites frequently occurs in stumpy prisms or in blades which are frequently of large size, in the green beds small needles of actinolite take the place of the hornblende. The constancy of the actinolitic character, and the absence of variation in the grain of the rock, are features which distinguish them from the epidiorites when other methods of distinction are wanting.

2. *Distribution and Field Relations.*—In the explanation of the map (Sheet 37) which lies immediately to the south, it was pointed out that the main Green Bed zone which had been traced across Cowal diminished considerably in the north-east of that sheet; so that, instead of the Green Bed material being about equally apportioned with the associated mica schists, it was merely represented by a parallel set of attenuated seams. In that memoir it was stated that the Green Beds were not confined to the main group, but that similar bands were more sparsely distributed in the schists dividing the main group from the Loch Tay limestone, and in the garnetiferous mica schists which succeed that limestone. Beyond the main zone, however, these Green Beds were not sufficiently represented to be differentiated on the map. In their north-easterly prolongation into Sheet 45 the Green Beds of the main group have so diminished that they are not so strongly represented as those intercalated in the schist zones lying to the north-west, and which have not been differentiated. Hence we find them more strongly developed in the garnetiferous mica schists than in the schists south-east of the limestone. To some extent their feeble distribution in the latter may be due to the contraction of the band caused by the intrusion of the Glen Fyne granite, and to the action of the Glen Fyne fault.

In the northern part of Glen Fyne shown upon this map, for a distance of a mile, Green Beds occur in contact with the limestone, but have not been observed east of that bed, which is only separated from the granite by a distance of about 200 yards. Along this line, however, narrow green bands of fine-grained hornblende schist are frequently found associated with that limestone. In the Alt na

Faing, near Inverchorachan, a few thin seams of folded hornblendic schists of this type occur east of the limestone; the most distant seam from that mass, however, is only separated from it by 15 yards. To the south of Inverchorachan only one small green bed has been observed east of the Loch Tay limestone.

In the garnetiferous mica schists, Green Beds, although more abundant, are yet only feebly developed. They occur on the eastern boundary of the map near the head of Glen Fyne as hornblende schist, retaining no traces of clastic structure, but preserving traces of original sedimentation as shown by banding. It is a fine linear foliated hornblende schist, and is seen under the microscope (5683) to consist of green actinolitic hornblende, highly dichroic, and clear yellow green to deep green and bluish green. Felspar is exceedingly abundant, and its decomposition has given rise to secondary micas. Quartz is comparatively scarce, and there is a good deal of iron oxide in irregular patches. In that part of the garnetiferous mica schist, for a distance of  $1\frac{1}{4}$  miles, extending south to the Alt na Faing, exposures of Green Beds are found which exceptionally have a breadth of outcrop of from 30 to 40 yards, a band of which occurs in that burn one-third of a mile distant from the limestone. Actinolite is fairly abundant, but does not enter largely into the mineral composition of the band. The other Green Beds are found nearer to the limestone, rarely exceeding 200 yards from it. For instance, in the burn half a mile north of Inverchorachan a band 40 yards wide of massive hornblendic green bed occurs, which contains small garnets. In the small stream immediately to the south, which flows likewise transverse to the strike of the schists, two very fine-grained hornblendic schists of this group are seen, one of which is twenty and the other ten yards broad, while in the immediate neighbourhood there are a few impure seams—that is to say, transitional beds between Green Beds and mica schists, sufficiently charged with chlorite and epidote to link them with the former.

### iii. LOCH TAY LIMESTONE.

1. *Lithological Characters*.—This important member of the Highland sequence forms a persistent band that stretches right across the Highlands. It consequently possesses a stratigraphical value that cannot be over-estimated in its relations to the crystalline schists with which it is associated. It divides the schistose group just described from the garnetiferous mica schist group which succeeds it. Moreover, the parallelism of both groups with the limestone confirms the conclusion that they occupy definite stratigraphical horizons.

The rock is holocrystalline and varies in colour from blue to grey, and is thin-bedded. It sometimes contains white mica and occasionally pale grey garnets.

2. *Distribution and Field Relations*.—This band enters the eastern margin of the map at the bottom of Glen Fyne, and pursues a south-south-westerly course along the western slopes to the



southern margin of the sheet under the ridge of Beinn Chas, where it occurs at an altitude of 2000 feet. Like the schists with which it is associated, it is much folded, but the folded limbs have a prevailing north-north-westerly dip. In spite of this plication its strike is remarkably even, and it would appear that the amplitude of the folds has been neutralised by the high angle at which the band is truncated by the ground surface. For about a mile along the extreme north-east it is frequently associated with green beds, as may be seen in the sections of the small tributaries of the river Fyne which dissect it transverse to the strike. It has been faulted by the Glen Fyne fault at the head of that glen, and occasionally by transverse or north-west faults further to the south-west. In the small stream about 1500 yards north-north-east of Inverchorachan the limestone has been thrown to the east by a north-west fault, so that the section exhibits two limestone bands divided by a green bed. About 500 yards still farther to the north-east a burn section likewise shows two limestone bands probably due to faulting rather than plication. Its widest outcrop is seen in the Alt na Faing above Inverchorachan, where it is very hard and thin-bedded, with a dip of  $50^{\circ}$  to the north-west, and has a breadth of about 35 yards. In this area such a breadth of outcrop is unusual, as it rarely exceeds a dozen yards and is often much less. In many parts of its course it has been much altered and indurated, presumably by contact metamorphism, as it occurs close to the granite margin. As far to the south-west as Inverchorachan it can be easily traced crossing the numerous burns, and is sometimes exposed on the slopes that intervene, but beyond that locality it has not been so continuously traced, due to surface debris. On its reaching, however, the higher ground to the south-west, where the rocks are bare, the band can be easily followed.

#### iv. GARNETIFEROUS MICA SCHIST.

1. *Lithological Characters.*—This group forms a band on the north-west side of the Loch Tay limestone, separating the latter from the Ardrishaig phyllites. It consists of an assemblage of gneissose grits, granulitic gneisses, and mica schists, differing mainly from the group of schistose rocks south-east of the green beds (described in Section i.) by the strong development of garnets. The band has suffered a similar degree of regional metamorphism, and has often undergone, therefore, a complete mineral reconstruction. On the whole it is, perhaps, less siliceous than the band below the limestone, and in part contains more chlorite. In the field, however, extensive developments of gneissose grits are seen in which the original clastic character is obvious, not only by the partial preservation of the clastic grains, but by the interbanding of beds of diverse composition and texture that marked the original deposit.

The most striking characteristic of these rocks is the remarkable development of red garnets scattered broadcast over the group. They are not, however, uniformly distributed, but bands thickly



charged with this mineral alternate with others in which it is comparatively rare. In size the garnets range from a quarter of an inch downwards. Notwithstanding that the garnet is a metamorphic product, its introduction, in part at least, preceded the close of the schistose epoch, as its partial destruction by the schistose movements makes clear. Not only do the foliation planes tail round them, but they are frequently crossed by fractures which have been infilled with quartz. Moreover, they are often partially or entirely replaced by chlorite, and these pseudomorphs often form lenticles that tail at their extremities parallel with the foliation of the rock. Garnets are most numerous in the softer beds which are characterised by a preponderating development of micaceous and frequently chloritic material, in which they are so thickly aggregated as to form a large proportion of the mass. This is more especially brought out where they have been replaced by pseudomorphs of chlorite, which give a striking green hue to the rock. Garnet has not been observed to occur massive as in some of the garnetiferous greenstones of Cornwall, but occurs as individual crystals more or less idiomorphic.

Actinolite is of frequent occurrence in these rocks, but although like garnet it has sometimes been replaced by chlorite, this mineral appears to have been introduced after the cessation of the movements. In some instances, however, chloritic pseudomorphs after actinolite have been penetrated by garnets, and in all probability the period in which the latter were formed was of longer duration than that attending the production of actinolite.

The garnets in this group of rocks seem to play a similar rôle to that of the albites in the schists below the Loch Tay limestone. As the albites, however, show no mechanical change they are clearly of later introduction, taking them as a group, but may not have been later than the formation of some portion of the garnetiferous zone. The restriction broadly of these minerals to stratigraphical bands appears to point to original chemical differences in their composition. It must not be understood, however, that they are strictly confined to stratigraphical horizons. The garnets, for instance, sometimes extend to the upper portion of the schists below the Loch Tay limestone. They are also found in the overlying groups of the Ardrishaig and Loch Awe series, but in these latter their occurrence is more local, whereas in the garnetiferous mica schist group the presence of garnets is the characteristic feature over the larger part of their extension in the Highlands. In the Explanation of Sheet 37 it has been pointed out that along their south-westerly extension the garnets gradually die out, or are only microscopic, but this feature is general the further they are traced to the south-west, where regional metamorphism has diminished.

2. *Distribution and Field Relations.*—This group occupies a strip of about four miles on the eastern margin of the map, from the slopes of Beinn Laoigh to the head of Glen Fyne, from which the band extends to the southern portion of the sheet along the precipitous slopes of Beinn Bhuidhe. In the Geology of Cowal and the Explanation of Sheet 37 it has been shown that, whereas the

schists have been folded to a high degree, the boundaries of the larger rock bands or groups follow a course singularly regular. The garnetiferous mica schist group in its extension from Cowal into Sheet 45 preserves this regularity until it approaches the head of Glen Fyne, when its junction with the Ardrishaig phyllites is curved until it leaves the sheet above Glen Lochy. The curved junction forms a double fold, the southern apex of which brings the junction half a mile to the westward in the valley between Ceann Garbh and Meall nan Tigearn. The margin then, after looping round to the eastward of the latter hill, sweeps round to the north-west, crosses the Allt a' Chabrain burn at a distance of  $1\frac{1}{4}$  miles from Socach, where it bends round to the north-east along the flanks of Beinn Laoigh, that peak and its upper slopes being formed of garnetiferous mica schist. It is only along the eastern slopes of Glen Fyne that both edges of the band are seen in this map. In the southern part of the sheet the group has a width slightly exceeding a mile, but the north-eastern portion of the band at the head of Glen Fyne has contracted to half that amount. To the south of Meall nan Tigearn the boundary has been shifted by a fault a quarter of a mile to the north-north-west.

The group contains some green beds which have been already described. It is comparatively free from igneous rock. It contains a few bands of epidiorite near its western margin below Beinn Bhuidhe. A boss of kentallenite occurs on the southern edge of the sheet, and a few dykes of lamprophyre and basalt are scattered over the area.

This group is less siliceous as the Ardrishaig phyllites are approached, and where they are also very chloritic it is often difficult to define the boundary between the two groups. The difficulty is accentuated when the chloritic and micaceous zones of this group are not garnetiferous. In the sheet to the south (37) a small zone of graphitic schist has been adopted as the boundary; but on leaving the coast and tracing the beds into the mountainous district represented in this sheet (45), the graphitic schist is too feebly developed to preserve its individuality. In the area between Beinn Bhuidhe and Beinn Laoigh, not only has regional metamorphism sharply advanced, but the same district has also been subjected to a higher degree of mechanical disturbance; as a consequence, the graphitic schist has been, as it were, enveloped in the garnetiferous schist, and is represented in the latter for a breadth of from a quarter to half a mile by a series of infolds. It is seen in the burn which forms the head waters of the river Fyne, about one mile N.N.E. of Ceann Garbh. It is also seen in the burn sections on the slopes below that peak and Beinn Bhuidhe and in the upper part of the Brannie burn.

At An Caoran, and on the slopes of Beinn Laoigh, there is a large development of quartzose beds, and both garnets and actinolite are often replaced by chlorite. This is seen also at Meall Reamhar, but at this locality fresh idiomorphic garnets are seen within the pseudomorphosed actinolite, their boundaries often extending beyond the margin of the latter mineral. Here also

garnets are frequently seen with chloritic rims, which form tail-like extremities. In the Alt na Faing burn the chloritic pseudomorphs after garnet are so extensively developed as to give a prevailing green colour to the rock. Moreover, some of the pseudomorphs show as lenticles with tails, and chlorite has also replaced actinolite.

Along the slopes below Ceann Garbh garnets are often strongly developed in massive quartzose beds, as may be seen half-a-mile to the north of Inverchorachan. Near the same locality ( $\frac{3}{4}$ -mile N.N.W. of Inverchorachan) zones of schist a foot in width are almost entirely composed of garnets. The schists immediately below the limestone are garnetiferous in the Alt na Faing burn, and on the hillside further to the southward above An Caorachan. Quartz segregations are numerous, and as they have become involved in the folding the intense plication of the schists is well marked.

This group of rocks has undergone a vast amount of contortion, which has involved not only the bedding, but the planes of foliation also. Moreover, the larger folded limbs have been crumpled, and, as already shown, the earlier quartz veins have shared in this plication. As a result of this extreme contortion, combined with an advanced type of metamorphism, they have given rise to singularly rugged scenery, which is well brought out on the watershed north-east of Beinn Chas. There the contortion is so pronounced that in the absence of deep sections there is no indication of the general dip. Moreover, the folded limbs have been squeezed and flattened and the quartz segregations of the veins have been reconstructed. At Meall Reamhar, at the head of Glen Fyne, the rocks are in a similar state of contortion. As a general rule, however, in spite of contortion there is a prevailing dip rudely perpendicular to the strike of the band, and varying with its sinuosity. This dip is to the N.N.W. from the southern margin of the map to the head of Glen Fyne, when the boundary with the Ardrishaig phyllites is folded, as already described. Henceforward the dip, while still inclining generally towards that boundary, is more variable.

J. B. H.

## CHAPTER IV.

### METAMORPHIC ROCKS—*continued.*

#### V. ARDRISHAIG PHYLLITES WITH THIN LIMESTONES AND QUARTZITES.

This group, which succeeds the garnetiferous mica-schists and lies between the latter and the Loch Awe group, is extensively developed on this sheet south of Glen Lochy, the Strath of Orchy, and the head of Loch Awe. On the eastern margin of the map it forms a narrow strip only a quarter of a mile in breadth on the slopes of Beinn Laoigh. Following a direction a little to the south of west as far as Socach, it then bends round to the south-east, following the fold of the garnetiferous mica-schist group already described. It increases in breadth until at the apex of that fold it has a width exceeding a mile. Again contracting from that apex, the south-eastern limb of that fold is reduced to a breadth of half a mile for a very short distance, when it is suddenly replaced by a compound fold, which has the effect of bringing the Ardrishaig phyllites to the surface over a broad stretch of country extending from Beinn Bhuidhe to the head of Loch Awe. There the boundary again swings back from Ra Creag in a west-north-westerly direction to Dalmally and the delta of the Orchy. From thence it follows the north-eastern shore of Loch Awe, crosses the loch in the Pass of Brander, enclosing a small area in Lorne south of that Pass, and recrosses the loch in the neighbourhood of Inistrynich. From that point, after following an easterly direction for over three miles along the basin of the Teatle Water, it suddenly deflects to the S.S.W. near the hill of Bealach nan Cabrach, and pursues a fairly uniform course to the western slopes of Glen Shira on the south of the map. The south-eastern boundary of the group from the slopes of Beinn Laoigh to those of Glen Fyne coincide with the boundary of the garnetiferous mica-schist series already described. The group, therefore, lies in a tract forming a great loop of comparatively low-lying country to the west, while its eastern extension forms a mountainous country that includes the peaks of Beinn Bhuidhe (3106 feet), Ceann Garbh (2635 feet), and Meall nan Tigearn (2423 feet).

These peaks lie just within the eastern margin of the group, and constitute the most elevated ground of that portion of the sheet lying south of the Strath of Orchy and the Pass of Brander. From that eastern range of hills to the shores of Loch Awe, a distance of nearly eight miles, the declivity is far from uniform. At a distance of about three miles from the eastern boundary there is a line of hills parallel to that boundary, the peaks of which attain



an approximate altitude of 2000 feet, viz., Beinn Bhalgairean (2085 feet), Beinn Bhòidheach (1933 feet), and Beinn an Sithein (2088 feet). That line of peaks approximately divides the group into two equal portions. From their base to Loch Awe it occupies comparatively low-lying country in the basin of the Teatle Water, and for a distance of three miles from Loch Awe the maximum elevation does not exceed 700 feet. Attention has been particularly directed to the partition of the group into elevated and low-lying divisions, as these also form areas of distinct lithological type due to marked differences of metamorphism. The western or Loch Awe area having been metamorphosed but slightly, whereas the eastern or mountainous area has undergone an extreme degree of metamorphism, the lithology of the group varies considerably. Not only are these distinct types represented by phyllites on the one hand and by coarsely crystalline schists on the other, but transitional forms connect these two extremes.

In common with the Loch Awe group, it is associated with large masses of igneous intrusions, consisting mainly of epidiorite and allied rocks, that are fairly uniform in their distribution over the group. A small intrusion of granite occurs on the ridge connecting Beinn Bhuidhe and Stac a Chuirn; a boss of kentallenite is seen near the head of Glen Shira; and dykes of basalt, lamprophyre, and porphyrite are sparingly distributed over the area.

The group consists essentially of calcareous phyllites, with small bands of impure limestone and some quartz-schist and quartzite. These *Ardrihaig* phyllites contain a very low percentage of silica and a large amount of lime, and in their normal condition constitute one of the softest rocks of the Highlands, being readily scratched with the finger-nail. They are usually of a pale-green colour, but are often blue and sometimes grey or even pinkish. They are too soft to form roofing slate, and lend themselves readily to erosion. In areas of extreme metamorphism, however, induration has produced a rock exceedingly tough, that resists weathering to such a degree as to form high and mountainous country. The rugged range of Beinn Bhuidhe, forming the highest ground between Loch Awe and Glen Fyne, is carved out of these rocks.

Sericitic mica enters mainly into their composition, except in areas of slight metamorphism, where the rock is almost a clay slate. In areas, on the other hand, of extreme crystallisation, chlorite and muscovite have differentiated into large plates, so as to impart a mottled appearance to the rock. The green plates may not always consist entirely of chlorite, but, in any case, the chlorite, instead of being uniformly diffused through the rock, has aggregated into plates of which it must be the principal if not the sole ingredient. Biotite is sporadically developed in areas of increasing metamorphism, and where the latter is of a high degree garnets also occur. They are never so highly developed, however, as in the group of garnetiferous mica-schists, either as regards size or aggregation. Epidote is a common constituent in the metamorphic districts, especially in the more calcareous varieties.

Although the *Ardrihaig* phyllites are highly calcareous, lime-

stone bands of any size are rare. They occur as fine bands intimately mixed with the phyllites and siliceous members, and ranging in thickness from a few feet to the finest laminations. The limestone is very impure, and although dolomitic in appearance, usually effervesces with cold hydrochloric acid. The weathered colour is rusty brown, while a fresh fracture varies from buff to pale yellow, and exceptionally white. Besides forming bands, much calcareous material is diffused amongst the phyllites and quartzites.

The quartz schists and quartzites are very compact, and the texture so fine that clastic structures are often not to be detected, even in areas of slight metamorphism, whereas in highly altered districts they are never present.

The quartzose bands, when foliated, are highly siliceous, with very thin films of mica along the cleavage planes, and closely resemble fissile quartzites. More normal quartz schists also occur, and there are transitional types connecting the siliceous and argillaceous members. The matrix of the siliceous members is often to some extent calcareous, and when the lime has been removed by solution the imperfect cohesion of the siliceous grains leaves the rock friable and easily decomposed. The siliceous bands vary in thickness from two or three feet to an inch or even less. Moreover, their occurrence among the phyllites is irregular, and they can seldom be differentiated on the map. They vary in colour from pale grey to grey buff. They may be distinguished from the siliceous members of the succeeding Loch Awe groups by their more uniformly fine texture and the usual absence of clastic grains, and especially by the absence of a coarser basal member. Finally, dark slate inclusions and partings, while characteristic of the Loch Awe group, are of rare occurrence in this series.

In describing the Ardrishaig phyllites of this area, it will be most convenient to commence with the less altered beds of Loch Awe, and from thence to trace the changes in their crystalline condition as they are followed easterly to the flanks of Beinn Laoigh. The beds occurring on the western side of Loch Awe, in the corner formed by that loch and the Pass of Brander, are comparatively unaltered. These rocks in their least altered forms can be best seen between Tervin and Hayfield. The beds are much folded, with dips of folds at various angles; yet the series as a whole is nearly horizontal, so that one particular zone may occupy a large area. Along the Pass of Brander, within the aureole of contact metamorphism of the Ben Cruachan granite, much hornfelsing has taken place which has been described in Chapter X., so that towards that Pass from Kilchrenan the change of crystallization is sudden and rapid, but much of that alteration may with certainty be assigned to contact metamorphism. From this western area, however, to the eastern, the change has been more gradual and uniform, and we are dealing with that type of metamorphism which is understood by the term regional. In their least altered state the Ardrishaig phyllites are well displayed on the southern coast of the Pass of Brander, at New Inverawe. Here they occur as grey and

greyish-green phyllites, lying nearly flat, with the strata sometimes rolling. They are made up of thin interlamination of phyllite and limestone, in which the former substance predominates, and in places the phyllites very closely approach the condition of clay-slates. They split along cleavage-planes which display a lustrous surface due to the development of sericitic mica. The latter mineral does not occur in definite recognisable crystals, but is sufficiently abundant to produce on a fresh surface a distinct lustrous sheen. On weathered surfaces, however, mica is not visible, and the rock cannot be distinguished from a clay-state. Notwithstanding the cleavage, the bedding is perfectly clear, colour banding being sufficiently prominent, even when the rock is in its most homogeneous condition. The surfaces of the cleavage planes are smooth, and usually quite free from puckering. Besides the thin limestones, very fine-grained quartzites and quartz-schists are intercalated, and are well displayed in the burn sections immediately west of Tervin. As we proceed along the strike, the group is now met with in Eilean Beith and Fraoch Eilean, two small islands on the north of Loch Awe, opposite to the entrance of the Pass of Brander. Here it is composed of green, highly calcareous slates, associated with very fine-grained quartzites and hornblende-schist, the sediments being in precisely the same unaltered condition as at New Inverawe. Following the line of strike still further eastward, they reappear on the eastern shore of Loch Awe at Lag-na-Luinge as greyish-green phyllites associated with thin limestones, and still in a similar condition of metamorphism to their counterparts on the western side of the loch. As the group approaches Dalmally, while some zones still retain their unaltered appearance, the beds on the whole are more crystalline. In place of the uniform greyish-green tint on a fresh surface as seen at Inverawe, the colour is less uniform, consequent on the development of scales of chlorite and the differentiation of that mineral from the mica. A mile still farther east, in the burn that passes the Dalmally Hotel, crystallization has advanced so far that they are in the condition of mica-schists, with white sericitic mica well developed on the planes of foliation, and that mineral together with green chlorite well individualised. In addition, biotite appears in long blades and irregular blotches, of later age than the schistose movements, which have not affected them. Still farther eastward, the micaceous beds assume a more silvery appearance by the increased development of white mica. The bedding has now become intensely puckered, steady dips being no longer discernible. Although the group as a whole persists in a fairly even course, the plication within the zone is enormous. The beds are also assuming a more indurated condition, weathering out into crags, instead of the smooth features further to the west. Approaching the neighbourhood of Beinn Laoigh, these beds are not only intensely puckered and more coarsely crystalline, but they are also considerably hardened. At Socach, about three miles east of Dalmally, these processes of deformation have proceeded so far as to recall the advanced type of metamorphism in the anticlinal district of Cowal;



the crystallization is very coarse, large flakes of white mica and chlorite or green mica being interleaved. They contain here a large amount of segregated quartz, which is both folded and crushed. Unaltered biotite is also abundant, especially in the calcareous zones, and small garnets occur in the indurated calcareous sericite schist. An excellent section of this coarsely crystalline schist is seen in the Eas à Ghail burn near Socach. From here this group has been traced to the north-east into Perthshire, where they have been mapped along the South-west Highlands as calc-sericite schists, in some portions of which the metamorphic condition is such that the sedimentary character has been entirely destroyed.

The intense plication of the areas of extreme crystallization is well brought out on the map in the mountain range marked by the peaks of Beinn Bhuidhe and Ceann Garbh. In this area the calcareous sericite schists, with a few quartzites and an occasional thin limestone, besides having a highly indurated and gnarled surface, are so squeezed and contorted that over a large tract no idea can be obtained of the dip. This tectonic confusion is admirably illustrated by the epidiorite intrusions. These rocks over the area generally follow well-defined bands parallel to the sedimentary groups; moreover, when these igneous bands have been repeated by folding, the duplicated limbs still tend to conform to that parallelism. On the mountainous tract of Ceann Garbh, however, there is no such orderly arrangement. Notwithstanding that the epidiorites there are of a particularly massive type, which in areas less metamorphosed have resisted the stresses, they have been rolled up and squeezed and forced to accommodate themselves to the most irregular plication. Instead, therefore, of presenting a longitudinal system more or less parallel, these rocks assume fantastic and irregular shapes, with numerous isolated lenticles and constantly-changing forms of the individual exposures.

A portion of the ridge to the south-west of Beinn Bhuidhe has been hornfelsed. Between that peak and Stac a Chuirn a small intrusion of granite is laid bare, which, in all probability, forms part of a very much larger mass that is lying close beneath the surface, and to which the contact metamorphism can be attributed.

## vi. LOCH AWE GROUP.

### AREA SOUTH OF LOCH AWE.

*Lithological Characters.*—This group is divided into two parts by the compound fold into which the Ardrishaig series has been thrown, by which the latter, after following a north-easterly direction, has been deflected westerly to Loch Awe. The main portion of the group in this area extends for about eight miles along the coast of Loch Awe from the southern edge of the sheet to near Inistrynich. From that place, after stretching easterly as far as Bealach nan Cabrach, it bends back to the western slopes of Glen Shira. The other area occupied by the



group lies on the northern side of the boundary of the Ardrishaig series between Dalmally and Ra Chreag.

As was pointed out in the last section dealing with the Ardrishaig group, the petrological characters vary considerably by the unequal action of regional metamorphism. The latter group on its easterly passage from Loch Awe increased rapidly in crystallization. The Loch Awe group, likewise, that lies south of the Ardrishaig band differs markedly from its folded extension which appears on the north side of that band. The continuity of the group, however, on the east side of Loch Awe being cut off by the deflected Ardrishaig group, the increase in metamorphism can only be traced from the southern to the northern portion of the Loch Awe group by passing over a portion of the latter. Hence the northern and southern divisions, instead of blending into one another by a gradual passage, are of different metamorphic characters. In the northern area, where the crystallization of the Ardrishaig group is of an extreme type, the associated Loch Awe group exhibits corresponding metamorphism, just as in the southern area the two groups partake equally of a lower degree of metamorphism.

The southern area will be described first, as the group is there more typically represented. This group, which is also strongly developed in that part of the Loch Awe basin lying to the south of this sheet, has proved of the greatest interest in unravelling the genesis of the crystalline schists of the Southern Highlands. Its systematic examination has enabled us to demonstrate\* that a great series of rocks that extend across the Highlands as typical crystalline schists pass along their strike by a gradual diminution in metamorphism into rocks lithologically resembling Palæozoic sediments. The sediments, in their unaltered form, frequently contain clastic mica, while their associated igneous bands display corresponding diminution in metamorphism, ranging from highly foliated rocks to others in which the original structure has been preserved.

The Loch Awe group consists of—

- (a) Limestone.
- (b) Black slates (sometimes graphitic).
- (c) Grits and quartzite.

The limestone is usually blue in colour, but varying to pale grey and even white, and to very dark blue and sometimes blackish hues. It is crystalline and stratified, generally very thin-bedded. It is often foliated with mica developed along the planes of schistosity. Shading into slates on the one hand and into grits on the other, it presents impure types varying in their composition in proportion to the amounts of argillaceous or siliceous material with which it has been mixed. When the argillaceous ingredient is sufficiently in excess it passes into calcareous slate, and difficulty has been experienced in differentiating these impure limestones,

\* *Quart. Jour. Geol. Soc.*, vol. lv. "Progressive metamorphism in the region of Loch Awe," by Mr. J. B. Hill.

which occupy the border-land between limestone and slate. There is a like transition from the limestones to the grits, the former being often thickly charged with pebbles of quartz and felspar. The limestone, moreover, is frequently of a fine, sandy type, tiny sandy laminations of original deposit being closely interbedded with the limestones. The limestone is frequently coarsely crystalline, but is in many instances of a fine granular or cherty type, and this is especially the case when associated with much black slate. All the various types may be met with in the same seam; slaty limestone, compact fine-grained, and the coarse gritty types with pebbles, an inch in length, succeeding one another in unbroken continuity.

The slates may readily be distinguished from the Ardrishaig phyllites. In their typical condition they range in colour from dark blue to black, while occasionally they contain sufficient graphite to soil the fingers. They are more homogeneous, harder, and more massive than the Ardrishaig phyllites, and in their normal condition are not calcareous. While these dark slates are undoubtedly the characteristic type, paler varieties sometimes occur ranging from grey to brown.

Over the Loch Awe group generally chlorite is rare, while in the Ardrishaig phyllites this mineral has imparted generally the colouration. Occasionally, however, the slates and grits of the Loch Awe group are green, and the clay slates can then only be distinguished from the Ardrishaig phyllites by their lithological characters. The green varieties, however, are only of local occurrence and do not occupy a definite horizon. Although the slates are frequently highly contorted, the cleavage is often perfectly regular, and they have been wrought for roofing slate.

The slates are often intermixed with siliceous material and gradually pass lithologically into grits. Not only is there a gradual passage into the siliceous members of the Loch Awe group, but these latter, even in their greatest development, are separated by argillaceous bands precisely similar to the main body of the slates, and this holds good whether the slates are green or of the more general dark blue or black type.

Occasionally the slate bands enclose pebbles of quartz and felspar, some of which are as large as those in the coarsest grit bands or gritty limestones, but on the whole they are of far rarer occurrence than in the calcareous beds.

*Grits and Quartzite.*—The siliceous members form the top of the Loch Awe group, and consist of grits almost coarse enough to be denoted as conglomerates, and fine-grained rocks such as quartzites. They have been variously affected by dynamic forces, some having been completely foliated while others are not even cleaved. As previously described, they pass gradually into the slates and also into the limestones, so that we have rocks of mixed composition which serve to bind the divisions into a single group. The grit bands are divided by partings of slate similar to the main mass of the argillaceous series, so that we are evidently dealing with a single system of deposition uninterrupted by any important

break. They are composed of pebbles of quartz and felspar, much of the former being of the clear blue variety. The latter is pink or dull white, consists of both orthoclase and plagioclase, the former often in excess, while usually quartz preponderates largely over the felspar. Coarser and finer pebbly bands rapidly alternate, the coarser, which are usually two or three yards and sometimes twelve yards in width, being made up of pebbles as large as almonds, which generally lie in a finer-grained matrix. White mica is not a conspicuous mineral except in the highly metamorphosed bands. In exceptional localities of feeble metamorphism, clastic micas have been preserved. The grits associated with black slate are sometimes dark, and those associated with green slate are green, but both are strictly of local occurrence.

True quartzites are rare in the Loch Awe region; many of the grits, however, are not far removed from quartzites. Every gradation is seen in the grits from bands which have suffered extreme granulitization to others in which the grains have suffered little or no crushing, and in which even the clastic micas are preserved. In the coarse grit bands the larger pebbles are often elongated and flattened, while the matrix has been partially or completely granulitized. Usually, however, crushing has been confined to the ground mass, and the larger pebbles show little or no alteration. Some of the finer grits, which in the field present no evidence of crushing, nevertheless when subjected to microscopic examination show that they have been modified to some extent by pressure. Through successive stages of alteration, however, we arrive at last at beds so unaltered that clastic micas are still preserved, and even microscopic investigation fails to detect evidence of crushing.

*The Boulder Bed.*—In addition to the lithological types already described, a rather abnormal conglomerate or boulder bed which occupies a fairly definite position across the Highlands from Aberdeenshire to Islay occurs within the Loch Awe group. It is extremely local in its occurrence, and most probably marks a phase of crustal oscillation which sufficiently raised the sea floor to admit of a certain amount of contemporaneous erosion, fragments of each variety of rock being torn up and rolled, and enclosed in a matrix of like composition, or when transported further have been deposited on sediments of unlike type. On the whole the deposit points to a distribution of the boulders from coastal margins to sediments formed in deeper water, the larger siliceous boulders being enclosed in gritty or quartzose-argillaceous sediments, and only occurring exceptionally as small boulders in the purely argillaceous or calcareous rocks. Slate boulders occur exceptionally in the grits, but are mainly confined to the limestones, while boulders of the latter rock are rarest of all, and almost entirely restricted to the limestone itself.

The presence of grit boulders indicates that the coarser siliceous deposits had to some extent been formed prior to the boulder bed, but there appears strong grounds for believing that the boulder bed and the coarse grits belong to the same general phase of



deposit, for besides the grit boulders which are, properly speaking, true rock fragments, the slates and limestones likewise contain pebbles of quartz and felspar identical with those entering into the composition of the grits, and sometimes attaining the size of two inches, while pebbles ranging from a half to one inch in length are exceedingly common. Foreign fragments in the boulder bed of this area are rare, but granite fragments have been exceptionally met with. These will be further alluded to in dealing with the local distribution of this series.

That the boulder bed represents an abnormal phase of deposition due to an elevation of the sea bottom and not an important unconformity may be inferred from the identity of the lithological types among which it occurs, and from the limestone in which it lies forming a continuous deposit with limestone of normal type. Moreover, the boulder bed lies within the Loch Awe group itself, and has not been found resting on the Ardrishaig phyllites.

In studying the marginal relations of the Loch Awe and Ardrishaig groups south of Shira, it is significant that the limestone, although usually sandy, rarely exhibits the coarse gritty character seen further to the west. Moreover, the black slate may be entirely absent or present in very limited amount. Further, the boulder bed has not been observed at that margin; so that, speaking broadly, the occurrence of the boulder bed, the gritty limestone, and black slate in appreciable quantity appear to hang together. Moreover, the marginal limestone, where not associated with black slate, is seldom of the dark graphitic hue which it assumes when in association with well-developed black slate. It appears, therefore, that the oncoming of these conditions, bringing about a change in sedimentation as the result of crustal oscillations, was less perceptible in this area on the eastern margin of the group.

#### GLEN SHIRA TO LOCH AWE.

*General Distribution.*—A very large part of this area is occupied by epidiorite, an extensive sheet of which practically covers the whole of the district west of the main road running south from Cladich and extending to the shores of Loch Awe. East of that line epidiorite, although not so extensively developed as the sedimentary deposits, occurs in considerable abundance.

Limestone is also represented in a series of parallel bands associated with phyllite over a belt of country extending from Glen Shira to Loch Awe, as far south as a line running from Cladich to Shira. To the south of that line grits and quartzites form the elevated tract that culminates in the peak of Beinn Ghlas. On the eastern margin of those quartzites along the slopes of Glen Shira limestone and black slate are but feebly developed, and in parts the latter may possibly be absent. On the other hand, the steep angle at which the hill slope truncates the bedding would to some extent account for the apparent diminution. In the vicinity of Shira and Sron Mor, where the ground is flatter, limestone forms large exposures in association with Ardrishaig phyllite. Excellent sections of the limestone are seen in the burn at Acurragh,



intimately mixed with Loch Awe phyllite, quartz-schist, and grit. In the vicinity of Lochan na Cruaich, and again one mile S.S.W. of that locality, the limestone in association with epidiorite is highly indurated and baked by contact metamorphism. Over this area the Loch Awe slates are so poorly represented, and the isoclinal folds are so steep, that they rarely occur in well-defined bands thick enough to be worth differentiation on the one-inch map. Consequently, the only two members of the Loch Awe group that have been represented are the limestone and the grits, the slates usually appearing either as partings within the grits or intimately folded with the siliceous or calcareous members with which they are associated. The apparent dip and foliation as seen in the various sections, although comparatively uniform, have no relation whatever to the geological position of the series as a whole, and for purposes of stratigraphy they must be altogether disregarded.

The base of the quartzite is well seen on the south side of Allt Fearnna, to the east of Inistrynich, where it rests upon grey silvery phyllites with limestone bands. The actual base is here often coarse and pebbly, and contains numerous fragments of limestone identical with that exposed immediately below it, and the junction, in the opinion of Mr. Kynaston, has all the appearance of an unconformity.

The boulder bed is exposed in the bed of the burn just east of Upper Sonachan, and again about a mile south of Cladich, in the latter locality lenticular grit boulders being embedded in a slaty matrix. About one and a half miles W.S.W. of Beinn Ghlas lenticles of gritty quartzite about a foot long are lying in a matrix of similar composition. In the vicinity of the small lochan three quarters of a mile south-east of Tom Bharra, some exposures of boulder bed are seen as inliers within the large epidiorite, one of which occurs as a conglomeratic limestone with pebbles of quartzite up to two inches in size.

#### STRATH ORCHY AREA.

The Loch Awe group which here succeeds the Ardrishaig group to the north is in a more advanced metamorphic condition than in the area just described. The quartzites are often flaggy and strongly granulitized, but the coarse pebbly bands, in which the original outline of the pebbles is still fairly distinct, are not uncommon, and are well seen on the north side of Glen Lochy near Socach. Apart from metamorphic condition, the principal feature in the group is the comparatively strong development of dark and sometimes graphitic schists which are interposed between the limestone at the top of the Ardrishaig series and the Loch Awe quartzites. They are well developed in Strath Orchy, but in their easterly continuation into Sheet 46 they are confined to a narrower zone, which may be traced along the south side of Glen Lochy. There are numerous infolds of the black schists within the quartzite and the latter is often folded with the black schists.

J. B. H.

## AREA NORTH OF LOCH AWE.

The area now to be described, which is occupied by the black schists, Loch Awe limestone, boulder bed, and quartzites on this side of Loch Awe, forms the roughly oblong strip extending from the south-east end of the Pass of Brander and the promontory of New Inverawe to Loch Nant. To the north-west of this strip the schists disappear beneath the Lower Old Red Sandstone lavas. The black schist is perhaps more typically developed in this area than in any other part of the map. It is very little altered, as far as composition is concerned, and occurs mainly in the form of black slates, which were formerly quarried for roofing purposes at Kilchrenan. The cleavage is not often at a higher angle than  $45^{\circ}$ , and lamination indicating the original bedding planes is often well marked, and lying frequently almost horizontal. The laminae do not show nearly such a high degree of puckering as in the more highly metamorphic areas.

The folding of the whole schistose series is of the isoclinal type, the folds being sharp and of no great amplitude.

There is no large area of black slates, and it has not been possible to map them out as definite zones, owing to the frequent infolds of limestone and quartzite, and the numerous intrusive sills and occasional boss-like masses of epidiorite. Perhaps the best exposures are in the small burn about a quarter of a mile south-west of Kilchrenan village. They occur again as a thin strip lying below the blue limestone south-west of Achnamady and between Achnamady and Achnacraobh. Numerous outcrops occur between Loch Tromlee and Loch Nant, showing a very distinct lamination and frequent intercalations of calcareous bands.

The *Limestone*, known in this area as the Loch Awe limestone, has been mapped out as a well-marked zone, with occasional bands of graphitic slate, from the high road one mile north of Kilchrenan, in a south-westerly direction past Achnacraobh and Achnamady, until it disappears, about a mile south-west of the latter locality, beneath the later volcanic rocks. The same belt appears again from beneath the volcanic rocks in a small inlier on the west side of Maol Mor, associated with the black slates. Between Kilchrenan and the Pass of Brander there are numerous outcrops of the limestone associated with black slates or grey phyllites. In the neighbourhood of Tervin numerous thin limestones occur associated with pale phyllites of the Ardrishaig type.

The limestone near Kilchrenan is quarried for road-metal, and in some places was formerly burnt in kilns, but these have now fallen into disuse. This is usually a fine-grained bluish grey crystalline limestone, but is often much intermixed with impure and more argillaceous bands, which appear to increase towards the Pass of Brander. When these impure bands occur the numerous small overfolds and puckerings are brought out with great clearness. When traced towards the Pass of Brander, the impure limestones are seen to have been affected by the Ben Cruachan granite, and gradually assume the character of hornfels, and banded

calc-silicate hornfels is well seen along the line of crags between Lochan an Cuaig and the base of the Lower Old Red volcanic series. The action of the granite upon these rocks will, however, be described more fully in one of the following sections.

To the east of Kilchrenan thin limestone zones are frequently seen folded beneath the epidiorites and chloritic schists; in fact, these later sills would appear to have been intruded at about the horizon of the limestone and black slates. The limestone, where in contact with a sill, has been distinctly metamorphosed, and is often full of chert-like bands.

The *Boulder Bed* is well developed in this area. It is seen on the shore of Loch Awe just below the Kilchrenan Manse, and again forming a well-marked line of outcrop to the west and south-west of Kilchrenan, where it is seen to rest upon the black slates. It is full of pebbles and boulders up to two feet in diameter, arranged with their longer axes parallel to the lines of cleavage in the matrix. The boulders are mostly of fine and medium-grained grits and quartzites, and occasionally of limestone and fragments of black slate. In the exposure on the shore near the Kilchrenan Manse fragments of limestone and dark schist are exceedingly numerous in a gritty matrix, and in the burn just west of Kilchrenan village the lower part of the boulder bed consists in places almost entirely of fragments of black slate. Derived fragments of igneous rocks also occasionally occur. Thus small pebbles of granite and granophyre were found in this bed to the east of Achnamady, and pebbles of a pale grey cleaved foliated rock occur in some quantity in the shore section near the Manse. (Plate II.)

All the boulders and pebbles, with the exception of those of black schist, are well rounded, as if water-worn, and the boulder bed evidently represents a normal conglomerate which has undergone considerable stresses from earth-movement. The boulders, while accommodating themselves to the strain, have shown greater resistance than the matrix, which has, as it were, flowed round them and past them under the shearing action. The boulder bed does not appear to be continuous or constant in its behaviour, but while it is almost invariably associated with the base of the quartzite, it would appear to rest sometimes upon the black slates and sometimes upon the limestone. In fact, the boulder bed or some type of pebbly bed so frequently accompanies the base of the quartzite and contains fragments of the underlying rocks that we have undoubtedly strong evidence that the quartzite series rests unconformably upon the limestones, black schists, and phyllites. Thus in the Kilchrenan area we have not only the boulder bed resting upon the black slates and containing numerous fragments of them, but, interfolded with the limestone close to the base of the quartzite, we frequently have strong pebbly bands composed of fragments of the limestone and small pebbles of quartz, felspar, and sometimes quartzite, and we have already referred to the pebbly bands at the base of the quartzite overlying the pale limestones and



grey phyllites of Ardrishaig type in the area south-east of Loch Awe. A pebble-bed of an analogous character occurs two miles south of Port Sonachan, but the relations of the bed are not seen owing to the surrounding area being occupied by epidiorite and chloritic schists. The matrix of this bed is highly calcareous, and the pebbles, which are usually small, consist of hard, well-rounded, fine-grained quartzites and fragments of felsite, with smaller fragments of pink felspar and grains of quartz. Further to the east, the base of the quartzite is seen overlying the grey phyllites of Ardrishaig type along the slopes on the west side of Glen Shira. Thus the general behaviour of the quartzite, with the frequent boulder bed or pebble bed at its base, has strongly the appearance of an unconformity and overlap.

*Description of some of the Boulders and Pebbles in the Boulder Bed.*

—Two of the quartzite boulders from the Boulder Bed, when examined in thin slices under the microscope [9059, 9060], were found to consist mainly of quartz grains, mostly well rounded, with a few turbid grains of both striped and unstriped felspar, enclosed in a fine-grained, usually quartzose matrix, sometimes exceedingly turbid, possibly from decomposed felspar. Some chlorite is also occasionally present, and small zircons are sometimes seen in the quartz grains. The quartz often shows strain shadows, but there is scarcely any appearance of schistose structure in the matrix. If an average quartzite boulder from the boulder bed is compared with the schistose grit or quartz-schist, with which the boulder bed is associated to the south-west of Kilchrenan, the two rocks will be observed to present on the whole a similar composition, but to show a marked difference in structure. Whereas there is little, if any, schistosity in the boulders examined, a section of the "Loch Awe grit" [9061] shows much stronger strain shadows in the quartz grains, a matrix of clear, finely-granulitic quartz, and partial granulitisation of some of the quartz grains, which act as "eyes" in the finer material, as it sweeps round them. The rock also contains two feldspars, and what appear to represent small drawn-out fragments of black slate. The boulders evidently escaped to a great extent the action of the dynamic forces, owing to the shearing strains being carried off, as it were, by the plastic matrix in which they were embedded.

The granitic pebbles from the boulder bed, referred to above, are seen under the microscope to consist mainly of a somewhat coarse type of micropegmatite, with some plagioclase and some interstitial chloritic alteration products [9286]. Another pebble from the exposure near Upper Sonachan was a fine-grained granophyre.

Sections were also prepared of some of the felsitic pebbles from the exposure near the Kilchrenan Manse and from the pebble-bed south of Port Sonachan. A section from the former locality [9058] shows phenocrysts of alkali-felspar in a pale brownish, finely-schistose matrix.

The feldspars are turbid from alteration, but often have good



outlines and show Carlsbad twinning, while they tend to lie with their longer diagonals parallel to the planes of schistosity in the matrix. Partially surrounding the phenocrysts is a finely granular mosaic, which, together with the felspar crystals, forms well-marked "eyes." Occasionally the felspars show cross fracturing. Some ovoid patches of granular quartz are also seen, which may possibly represent original vesicles. The ground-mass is foliated, exceedingly fine-grained, and has a somewhat fibrous appearance, owing apparently to the development of minute parallel flakes of biotite. The rock may very possibly have been a felsitic lava.

The pale felsite-like fragments from the calcareous pebble-bed south of Port Sonachan are seen under the microscope [9057-9060] to be cleaved felsites of a similar general type to those of Kilchrenan. They show small felspar phenocrysts, which probably include orthoclase, in a finely felsitic and more or less banded matrix, containing a few small quartz grains.

The occurrence of these igneous pebbles in the boulder bed is an interesting point, and serves as additional evidence in connecting this bed with the Port Askaig conglomerate of Islay and boulder bed of the Isles of the Sea.

*The Quartzite.*—The relations of the quartzite to the black schists and limestone have already been pointed out. In the Kilchrenan district it is rather in the condition of a schistose grit, and forms a well-marked band on the north-west side of the boulder bed close to Achnamady. Here the rock is frequently of a dark-grey colour, owing to the abundance of included fragments of black schist. From Achnamady it may be traced in a north-easterly direction towards Lock Tromlee. It is well seen in places round the shore of that loch and for a distance of about a mile to the north-east. Near Loch Tromlee it is often strongly cleaved. It is usually of a medium-grained texture, and the original grains of quartz and felspar may be clearly seen.

#### AREA BETWEEN CRUACHAN GRANITE AND WATERSHED ON N.W. SIDE OF LOCH CRERAN.

The larger portion of this area consists of black schists and phyllites with intercalated quartzose bands. Black schists and fine quartzites extend from the south side of Loch Creran up to the margin of the Ben Cruachan granite. All the more argillaceous portion of this series has been converted into hornfels by the granite. The exact limits of the hornfels area are naturally difficult to determine. Marked alteration into hornfels may be noticed at a distance of about a mile from the appearance of the granite at the surface, this phase gradually shading off into less altered rocks as the distance from the granite increases. The alteration is even perceptible along the shore of Loch Creran, near Creagan Ferry, a distance of two and a half miles from the nearest granite outcrop.

The black schists resemble on the whole those of the Loch Awe

area, but the most striking feature of this district is the large amount of quartzose material with which they are associated. In fact, the black schists and their associated quartzose beds constitute frequently a series of banded rocks, consisting of alternating bands and laminæ of argillaceous and quartzose material, and often occupying a considerable area. The rock may sometimes be a quartzose schist banded with black schist, or again a black schist full of quartzose bands. A hand specimen frequently shows the banding, often highly puckered, in a very perfect manner; while in the field the bands vary from a few inches up to broader zones which can be represented upon the map. These banded rocks are especially well seen on Ben Bhreac, on the east side of Glen Salach, and on the hills on the north side of Glen Dubh. The alteration into hornfels tends to accentuate the banding.

A well-marked zone of limestone of the Loch Awe type occurs at the mouth of the river Creran, on the north side of the loch, and may be traced from this point up the north-west side of Glen Creran. Above this limestone is a band of typical black slates, followed by a series of fine-grained quartz-schists and quartzites with zones of black schist. Further to the west along the ridge and western slopes of Beinn Churalain, the argillaceous zones increase in frequency and consist of grey phyllites; and gradually, with a still further decrease of quartzose material, we pass into a series consisting almost entirely of greenish and grey phyllites with merely subordinate siliceous bands. When traced to the north-east these phyllites appear to assume more the character of black schists, as if the one passed laterally into the other.

To the east of the head of Loch Creran the limestone is well exposed in Allt Buidhe, where it is associated with black and banded schists, changed into hornfels, and accompanied by thin quartzite bands. It is here a highly crystalline, bluish-grey or white marble, while the less pure portions are strongly banded and puckered, and converted into calc-silicate hornfels.

H.K.

#### AREA NORTH OF LOCH CRERAN.

*Ardrishaig Phyllites*.—Between the white limestone at Port Appin and eastwards to near the farm of Strathappin the ground is occupied by Ardrishaig phyllites with a general north-east and south-west strike. This belt is composed of dark-grey green phyllites with some lighter bands. It stretches to the south-west and composes the rough ground on both sides of Glacerriska Bay, and a continuation of the same beds also forms the island of Eriska. Between Strathappin Farm and Ledgrianach the white limestone is found at intervals. This belt of Ardrishaig phyllites between Port Appin and Shian Bay seems to occur as a compound anticline.

The limestone at Port Appin is a brown brecciated dolomitic rock which at the Free Church passes into the adjacent phyllites through a series of thin limey bands with phyllitic partings. These beds are continued to the south along the east side of Airds

Bay, and are also found on the opposite side of Loch Creran on the Eriska shore. This limestone lies at the top of the Ardrishaig phyllites, and is locally called the Appin limestone.

Specimens of the limestone from the knolls immediately north of the Free Church Manse at Port Appin were examined by Dr. Flett, who reports that the rock is a dolomite schist containing dolomite in grains and small imperfect rhombohedra, much granular quartz and scaly sericitic mica, a little chlorite, iron oxides, pyrites and sphene. The amount of dolomite varies considerably, and the rock passes gradually into a pale grey or greenish-grey phyllite with accessory carbonates.

*Black Schists.*—The black schists lie on the east side of the line shown on the map between Strathappin farm and the head of the raised beach at Shian Bay, and extend eastwards as far as the west side of Loch Creran. The black schist is associated with a large amount of quartzose material which is so interfelted with it that it is quite impossible to separate the two in a satisfactory manner. When the quartzose material attains any thickness it becomes a fine-grained grey banded quartzose rock, and the alternating series has a strong resemblance to the black schist group of Dalmally. The relation of these beds can best be studied in the railway cuttings around Cregan, where they form a dark, rusty grey rock composed of alternating laminae of argillaceous quartzose material. Here they occupy the whole of the south shoulder of Beinn Churalain. In some sections the rock is a quartz-schist banded with black schist, or again it may be a black schist full of quartzose bands. This "grey quartzite" is totally unlike the Schichallion or Banffshire quartzite. It is a fine-grained biotite quartzite, and its position has long been recognised as lying close to the base of the black schist group. Over this portion of the country its apparent thickness is largely due to isoclinal folding, although its original thickness was no doubt greater than further to the north-east. The little black limestone of Perthshire and Ballachulish is exposed on the cliff to the north-east of the Ruadh Garbh, and also in the railway cutting to the west of Cregan Station.

*Quartzite.*—On the north side of Loch Creran the Central Highland (Schichallion) quartzite is well exposed on the bare cliffs which surround the small area to the south-west of Port Appin. Here the rock is a white felspathic quartzite, very pebbly and brecciated with well-marked original bedding planes. The pebbles are well rounded and consist of white and blue quartz. Immediately to the south of Barriemore this quartzite rests unconformably upon several bands of phyllite and limestone. On the shore to the east of this point the white coarse pebbly quartzite contains included fragments of the adjacent limestone. On the south side of the Barriemore and Port Appin road the junction between these two rocks is clearly a line of fault.

J. S. G. W.

The quartzite at the roadside quarry above Port Appin pier is a granulitic aggregate of quartz with many clear grains of fresh microcline, a less number of orthoclase crystals, and a few small



zircon and grains of iron oxide. Granulitic structure has almost completely replaced the original clastic character of the rock.

J. S. F.

BENDERLOCH AREA.

*Ardrishaig Phyllite Group.*—On the Benderloch area the metamorphic rocks form the basis of the plain lying to the west and north of the Lower Old Red Volcanic plateau. They form long and often abrupt and isolated ridges which still retain the appearance of an archipelago of rocky islets, although now united by the deposits of the raised beaches. The members of the Ardrishaig phyllite group compose the western half of the peninsula of Ardmucknish. In common with the other metamorphic rocks, they are intensely folded upon north-north-east and south-south-west axes, and are either vertical or highly inclined.

As developed in this region, the group is chiefly interesting on account of its division into two parts, the one being phyllitic while the other consists mainly of limestone and dolomite, constituting the Appin limestone. The former, which is much the larger portion, consists essentially of phyllites and slates of a grey-green colour and well-banded character, the different laminae being distinguishable both by colour and texture. Beds of this type are exposed in the headland of Fionn Ard. The Appin limestone consists of several beds of white or yellow limestone or dolomitic limestone. Although much more massively developed in this region, these calcareous beds at once recall the thin bands so well known as occurring elsewhere in the Ardrishaig phyllite group. It is important to note that the Appin limestone differs widely in character from that of Lismore, which will be described later.

In Ardmucknish the Appin limestone is exposed along the north-eastern extremity of the coast and again in Camas an Fhàis, from which bay it may be traced inland by means of limited exposures.

*Black Schists or Easdale Slate Group.*—The striking feature of the black schists in the Benderloch district is the frequent intercalation of quartzite bands in the group. This is, perhaps, best exhibited in the sections exposed along the shores of Loch Creran eastwards from Ruadh Garbh. The quartzites are generally fine in texture, but occasionally they are pebbly and contain grains of blue and white quartz, and also of felspar. Pebbly beds with a dark argillaceous matrix also occur. The quartzite usually forms bands of considerable thickness, which are almost always separated by thin partitions of slate. Thicker intercalations of slate and others of dark limestone also occur with the quartzite, while gradual transitions of quartzite by interstratification with black slate may be studied in many clear sections. There is, probably, much repetition due merely to folding of the strata, but there can be no doubt that the alternation of sediments is mainly due to original deposition. Inland the quartzite bands frequently project as ribs on the hill slopes, and are well exposed in the rock cuttings along the railway.



The black slates are lustrous and graphitic, with abundant cubes of pyrites, and closely resemble those wrought at Ballachulish and Easdale. Its thin limestone bands are in many cases similar to the little beds of black limestone which are a characteristic feature in the slate quarries of Easdale and Belnahua to the south-west, and Ballachulish to the north, of the present area. Occasionally the limestones are more sandy and light-coloured.

The correlation of this rather heterogeneous group with that of the black slates of Easdale and Ballachulish is strengthened by the fact that the Loch Creran exposure is one of several which serve to connect up the two typical areas.

Inland exposures of the members of this group are not so satisfactory as that just described, especially as regards the black slates, which are largely concealed by superficial deposits. The thicker intercalations of quartzite give rise to ridges, several of which have been cut through in the construction of the railway that traverses the area.

Members of the group appear from beneath the escarpment of the Old Red Volcanic and sedimentary rocks, and in a very disturbed and crushed condition form hillocks on the east side of Ardmucknish Bay, one of which marks the site of Beregonium or Selma, a stronghold of the early Irish colonists. On the west side of Ardmucknish Bay the black slates form a narrow fringe along the shore of Garbh Ard. Most of this last-named headland is, however, composed of quartzite whose relations are obscure. The quartzite is a white, fine-grained rock arranged in thin beds. Pebbles are very rare and intercalations of black slate are almost unknown, but greenish beds of a somewhat phyllitic texture are not at all uncommon. It is, therefore, apparent that in character it does not agree with the quartzite intercalations in the black slate group which are so well developed along the shores of Loch Creran. On the western side of the Garbh Ard the margin of the quartzite, where exposed upon the foreshore, is separated from the Appin limestone by a few feet of black slates and limestone, but, unfortunately, there are signs of considerable movement having taken place near the junction line. Inland, however, by the roadside west of Lochan Dubh, the same junction is exposed where there is little sign of movement, but the black slates and limestone are absent.

On the eastern side of Garbh Ard the quartzite is in contact with the black slates of the Easdale group, and though there is a slight movement and brecciation near the junction, the amount of displacement may be inconsiderable, and the transition between the two rock types appears to be gradual. Elsewhere south of Loch Creran the junction is hidden under beach deposits. Although the evidence is inconclusive upon the point, it seems preferable in the meantime to regard the Garbh Ard quartzite as merely a particularly pure example of the quartzites of the Easdale slate group, and not a representative of the quartzite which has been described in various parts of the Highlands, *e.g.*, Islay, as constituting a separate unconformable group.

E. B. B.

## LISMORE ISLAND.

*The Limestone Schist.*—The portion of Lismore Island which is included within this sheet, is composed almost entirely of a bluish-grey, finely-crystalline limestone. The bedding is made apparent in the cliff-sections by the difference in weathering of bands of an impure argillaceous limestone and thin quartzose layers, which frequently alternate with beds of purer limestone. The rocks are thrown into numerous sharp, closely-packed folds, the limbs of which are rippled by smaller folds. The axes of plication trend north-east to south-west, parallel to the length of the island. The axial planes are vertical or dip to the south-east, but occasional folds thrown over to the south-east were observed. On the western side of the island the bedding is generally vertical, and the folds appear to be of greater amplitude than those seen elsewhere. The limestone is traversed by an inconspicuous cleavage, the planes of which are vertical or dip at high angles to the south-east. The argillaceous limestones show a slight puckering due to an incipient strain-slip cleavage. Scattered cubes of pyrites are common throughout the limestone.

The *Black Schist* crops out chiefly on the west side of the island, but also half-a-mile north of Sròn na Craoibhe and again below Cachilardrishaig on the east side. At the latter place it is graphitic. The outcrops run along the base of the cliffs beneath the limestone, and extend up into the cliffs in folds. On the neck of the peninsula lying to the north-west of Fennacrochan, the limestone completely arches over a series of folds in the black schist. In several other sections on the coast to the south-west of this the limestone may be seen arching over the black schist, the tops of whose folds reach from 3 to 4 up to 30 or 40 feet above high-water mark. In fact, wherever the relation between the two rocks can be made out, the limestone appears as the upper member.

Eilean Ramsay and the neighbouring islets are composed of limestone and black schist which have the same characters as on Lismore.

Eilean Dubh, lying between Lismore and Benderloch, is formed of isoclinally-folded beds of white and yellow quartzite, dipping at high angles to the south-east. Crushed quartz-pebbles are recognisable in some of the beds. At the southern end, where the strike swings round from its normal north-east to south-west direction to nearly due north to south, thin green phyllites with some pale quartzose limestone bands are intercalated in the quartzite.

H. B. M.

## INLIERS OF METAMORPHIC ROCKS WITHIN THE VOLCANIC PLATEAU OF LORNE.

*Oban, Glen Crutten, and Achavaich Inliers.*—In the Oban region the old floor of metamorphic strata upon which the Lower Old Red Sandstone and its volcanic rocks rest is repeatedly brought to the surface by means of a series of step faults aided by denudation, as

may be seen by glancing at Sheet 45 and the horizontal section (Fig. 1, p. 71).

The rocks which there enter into this old floor consist of black slates and limestones of the Easdale slate group. The beds are seen to be constantly repeated by folds of no great amplitude, which have a tendency to be isoclinal, as all the steeper limbs face the north-west, as shown by the limestone bands, while the strain-slip cleavage planes which affect the slates all dip steeply towards the south-east and S.S.E. The limestones are dark and slightly crystalline and micaceous, but the grade of metamorphism is nowhere high. The folding and cleavage of the slates and their relation to each other are admirably displayed on the shores at Oban, and also in the cliff at the south end of the town, where the road bends round into Glen Crutten. At this latter point the limestone bands which have been quarried help to show the type of folding. The limestones were also formerly wrought in a quarry a little to the south of the road, and also in knolls standing above the raised beach deposits a little further up Glen Crutten. The railway cuttings south of Oban Station also expose excellent sections of the contorted slates in places cut by sills and dykes of dolerite of Tertiary age.

A considerable inlier of these slates and limestone bands also occurs at Achavaich, between Oban and Connel, its presence there being evidently due to the same system of faulting as that which has produced the exposures at Oban.

*Kilbride Inlier.*—North-eastwards from Kilbride, about five miles south-east from Oban, there is an inlier about a mile long and a few hundred yards in breadth occupied by silvery-grey phyllites, black slates, and limestone, surrounded by volcanic rocks of the Lorne platform. The limestone bands, which are thin, dark, crystalline, and micaceous, are repeated by innumerable small synclinal folds, the axial planes of which dip uniformly towards the N.N.W. The dark slates and limestones probably represent the base of the Easdale slate group, and the silvery phyllites the top of the underlying Ardrishaig phyllites (fig. 1).  
B. N. P.

#### vii. GRANULITIC SCHISTS OF MOINE TYPE WITH BOTH MUSCOVITE AND BIOTITE.

This series occupies an extensive area in the north-eastern portion of the map on the east side of the Ben Cruachan granite. It is associated with two other zones of metamorphic rock, namely, (1) flaggy quartzite or quartz-schist, and (2) garnetiferous mica-schist.

(1) By far the larger portion of the area referred to is occupied, however, by the granulitic schists of Moine type. In Strath Orchy it is not difficult to separate these rocks from the quartzite further south-west. The quartzite has undergone extensive granulitisation, but still frequently shows original quartz and felspar grains of large size. It contains little or no biotite, while on the other hand the granulitic schists of Moine type show a



considerable development of biotite. ⑦ These latter schists maintain a uniform character over a large area, and consist of fine-grained granulitic rocks in which nearly all trace of the original clastic structure has been lost. They vary in colour from pale-grey or pink to dark-grey, the darkness of the shade depending on the amount of biotite present. The pinkish colours are apparently due to the large amount of feldspathic material occasionally present.

A quartzite of pronounced flaggy character and without any distinct original clastic grains is well seen near the foot of Allt Broighleachan, in Glen Orchy. It appears to be separated by granulitic schists of Moine type from the more massive and often pebbly quartzite which occurs lower down the glen, and in most field-sections it can be distinguished therefrom with comparative facility. On one of its margins it is bounded by these granulitic schists, while on the other it gives place gradually to the garnetiferous mica-schist (2), to be subsequently described.

Throughout nearly the whole of the area occupied by the granulitic rocks and flaggy quartzite small veins of pegmatite are common. They occur chiefly as small veins and strings of coarse red feldspar, usually associated with quartz, and often running along the joint planes and other lines of weakness in the schists. Some of the veins consist mainly of quartz. Besides distinct veins, isolated pockets and strips of feldspathic material are sometimes met with, and these appear to be more common in the more highly feldspathic schists on the west side of Glen Strae. As to the origin of these feldspathic veins and patches, it can hardly be considered as probable that they are due to the direct contact action of the granite, since they are frequently seen at distances of several miles from the contact, nor can they be considered as direct injections from the granite magma. It is possible, however, that they may perhaps be due to some kind of "granitisation," accompanied by the introduction of feldspathic material, which may have thus affected the rocks at a considerable depth. On the other hand, there is no doubt that these granulitic rocks originally contained a considerable quantity of feldspar which could have supplied the material for these structures. It may thus be more reasonable to suppose that they were formed by segregatory action affecting the original feldspathic constituents, and accompanying the cataclastic stresses and reconstruction of the rocks.

(2) In certain parts of this north-eastern portion of the map highly micaceous schists, often with both black and white micas, and frequently garnetiferous, are not uncommon. Thus, garnetiferous mica-schists may be seen in Glen Orchy just below the Falls of Orchy (near the foot of Allt Broighleachan), and they again form a well-marked zone to the east and south-east of Loch Dochard in the Black Mount. They also occur on the south-eastern slopes of Beinn na Sroine, between Glen Orchy and Glen Lochy. Lithologically, they often bear a strong resemblance to the garnet-schists which occur below the calc-sericite group to the



south-east of Glen Lochy and in the Glen Fyne area, but they appear to occupy a different stratigraphical position.

The following section of rather over a mile in length, passing through these schists, is seen as one ascends the burn situated  $1\frac{1}{2}$  miles south-east of Loch Dochart, in the north-east corner of the map:—

1. A greenish hornblendic schist or gneiss, the nature of which is somewhat doubtful. It has provisionally been classed with the later epidiorites, but it is not impossible that it represents a foliated impure limestone.
2. On the south side as we ascend the burn are dark grey biotite schists, the biotite often developed in elongated patches, apparently representing pseudomorphs after actinolite, irregularly distributed over the foliation planes. This passes into a schist with two micas, often gneissose, and with some small pegmatite veins.
3. Garnetiferous mica-schist, with two micas and numerous garnets, constituting a zone nearly half-a-mile in breadth.
4. Pale grey flaggy quartzites—a narrow zone.
5. About a quarter of a mile of silvery-grey mica-schists, with two micas and small garnets. These rocks are often very quartzose and contain knots and bands of quartzose material, and are well exposed at the east end of Loch Dochart.

The biotite schist (2) is seen under the microscope [8618] to be fine-grained in texture, and to consist mainly of biotite and quartz, with a small proportion of felspar, and occasional eyes of granular quartz and small garnets. The garnet mica-schist [8619] is considerably coarser, but intensely puckered and well foliated. It is rich in quartz and contains both white and brown micas, the former being slightly in excess, and a certain amount of felspar. The garnets have often been broken up and show but little of their original substance, being mainly represented by chloritic alteration products, biotite flakes, and granular quartz.

It is highly probable that the granulitic schists of Moine type are the equivalent of the Struan flags of the Central Highlands. The recent progress of the Survey in the Central Highlands and in Eastern Ross-shire has shown that the peculiar granulitic structure and composition of the Moine schists of the North-West Highlands, with their intercalated bands of muscovite-biotite gneiss, are reproduced among the rocks of the Central Highlands, of which the Struan flags form a characteristic portion. If, as may well be the case, we have here in Argyllshire the representatives of the Moine-schists, we might with good reason compare the garnetiferous mica-schists with the muscovite-biotite gneiss. H. K.

## CHAPTER V.

### OLDER IGNEOUS ROCKS.

Under the term of older igneous rocks will be described in this chapter those igneous masses which are of earlier date than the earth-movements which caused the folding and foliation of the rocks of the Highlands. These rocks will be seen from a glance at the map to be almost entirely confined to that portion of the metamorphic area which is occupied by the grey phyllites of Ardrishaig type, the black schist, limestone, and quartzite. They reach their maximum development in the area on either side of Loch Awe, and die out in a north-easterly direction. In the Glen Creran area igneous rocks of this class are also only developed to a very small extent. These rocks are almost invariably intrusive, and occur in the form of sills, now consisting of epidiorite, chlorite-schist, hornblende-schist, and similar types. Occasionally masses showing a more boss-like behaviour may be met with.

i. *The Epidiorites and Hornblende-Schists, &c.* — Numerous masses, behaving as sills, of epidiorite, chlorite-schist, &c., have been mapped among the metamorphic rocks in the area surrounding Loch Awe. Petrologically there is a large variety of these rocks, and several variations both in composition and structure may be met with in a single sill. The rocks are frequently markedly schistose in structure, especially towards the margins of the sills, though certain of the larger and coarser masses have retained their original structure in a remarkable degree. Often a single sill may be represented by several detached masses, owing to repetition by folding, or to the form of the ground combined with a flat type of isoclinal folding. Occasionally a mass of foliated basic igneous rock may cover a considerable area, as, for instance, on the east side of Loch Awe, on the southern margin of the map, but they more usually form elongated masses standing out as conspicuous ridges above the softer types of schist, though, on the other hand, irregularly-shaped and complex intrusions are often met with. The rocks may be fine-grained or coarse, and in colour are various shades of green, and occasionally almost black. A considerable variety of rocks have been included under the general term of epidiorite for convenience in mapping. A short description, therefore, of the relations and petrological characters of some of the principal types occurring in the Loch Awe area will be of some interest in this connection.

*Description of the Principal Types.*—A large elongated mass of chloritic schist occurs along the west side of Loch Awe to the

S.S.W. of Kilchrenan. It appears to have been intruded at about the horizon of the black slates and blue limestone. The rock appears to be thoroughly schistose throughout. Porphyritic feldspars are common, and in some places small nodules of epidote, about the size of peas and closely resembling amygdules, are exceedingly numerous. Frequently these amygdule-like bodies show scarcely any signs of deformation, although the surrounding matrix of the rock may be well foliated. Irregular patches of crystalline granular epidote are also of somewhat frequent occurrence. A specimen from near the central portion of the mass, about half a mile north of Fernoch, shows under the microscope large crystalline aggregates of epidote and a few traces of feldspar phenocrysts, in a schistose matrix of plagioclase feldspar, chlorite, and fibrous amphibole. Traces of feldspar laths are abundant in the matrix. The chlorite and amphibole are mostly confined to those parts along which the movement has been most intense. The slide shows amygdaloidal cavities filled with carbonates and quartz-mosaic. The rock may be called a schistose epidiorite.

In the area lying between the road leading from Kilchrenan to Glen Nant and the eastern end of the Pass of Brander the epidiorites are represented by a more massive and coarser type, which appears to behave frequently as a more boss-like type of intrusion. A similar type of rock is also seen on the opposite side of Loch Awe at Bovay, near Cladich. This may be termed the dolerite or diabase type. A hand specimen shows a coarse or medium-grained doleritic structure, though specimens from the margins of the masses are often schistose and finer-grained. A good example of this type occurs as a large mass situated three-quarters of a mile N.N.W. of Ballimore and within half a mile of the Pass of Brander. The rock is decidedly coarse, and shows clear feldspars of elongated columnar habit, unorientated, in a dark greenish matrix. A similar rock, but somewhat finer in grain, occurs a quarter of a mile north-east of Ballimore. Under the microscope [9049, 9050] the plagioclase, which is slightly cloudy, is seen to be frequently cracked and broken, the fractured portions being often shifted, as shown by the discontinuity of the twin lamellæ. The interspaces between the feldspars are filled almost entirely by secondary minerals, viz., greenish hornblende, chlorite, a pale greenish biotite, epidote, leucoxene, and carbonates. Apatite is accessory, and may occur in relatively large crystals with an elongated columnar habit [9049]. In the coarser and fresher of the two specimens a small quantity of what may possibly be original augite is present [9049]. This type of rock was doubtless originally a plagioclase-augite rock, closely allied to the dolerites and gabbros. Another exposure of epidiorite, a quarter of a mile south-west of Ballimore, shows large porphyritic feldspars, measuring sometimes over two inches in length.

These doleritic types of the Kilchrenan area frequently show a considerable quantity of biotite in addition to green hornblende

and chlorite [5523 and 5687,  $\frac{3}{4}$ -mile east of Kilchrenan, and 6921 and 6922, near Barbreck, Kilchrenan]. In some cases, as, for instance, in the rock exposed at Bovay and at Taycreggan, the biotite tends sometimes to be in excess of the other ferromagnesian constituents [5526, 8674, 8675], and resembles somewhat the brown mica so characteristic of rocks altered by large igneous masses. In this case, however, the biotite could not have been formed by contact action, as there is no later igneous intrusion of any size in the immediate neighbourhood. The biotite has more likely been the result of thermodynamic action, and has evidently replaced an earlier ferromagnesian constituent.

On the opposite side of Loch Awe occurs a large mass of igneous rock belonging to the "epidiorites," with a breadth of about four miles. The rock belongs, however, to the fine-grained type, and is schistose throughout its entire mass. Portions of the mass are conspicuously porphyritic, while other parts again show the vesicular or amygdaloidal structures already described from the rock near Fernoch. A specimen, from two miles S.S.E. of Portsonachan, of a dark, almost black, schistose porphyritic rock shows under the microscope [9052] phenocrysts of plagioclase, rather turbid, often broken, and occasionally showing a partial granulitisation. The phenocrysts have a strong tendency to a similar orientation. Some grains of green fibrous hornblende also occur, and amygdules of epidote, occasionally with chlorite in addition. The ground-mass is markedly schistose, and appears to consist to a great extent of minute lath-shaped crystals of plagioclase, though it is a good deal obscured by secondary products, and by an opaque material in long streaks and strips probably consisting of disseminated iron-ore. There are also some large grains of iron-ore, partially replaced by leucoxene. The rock may probably have been originally a basic type of andesite.

Not far from this locality there is a zone of rock, forming part of the same mass, which consists of numerous lenticular patches of a highly amygdaloidal rock embedded in a fine-grained greenish schistose matrix. The amygdules are filled with quartz and stand out conspicuously on the weathered surface. Under the microscope [9053] numerous amygdules, occasionally measuring  $\frac{1}{4}$ -inch in diameter, but usually smaller, are seen imbedded in a brownish turbid matrix. The amygdules are sometimes almost spherical, though often more or less elongated, so as to appear oval or almond-shaped. They are filled with crystalline quartz, forming usually a rather fine-grained mosaic, which becomes coarser towards the central position. Some of the amygdules contain calcite in addition to quartz, and occasionally some grains of epidote in their marginal portions. The ground-mass is very turbid, but appears to consist of very small felspar laths in a dark brownish matrix. No phenocrysts are seen. The rock has strongly the appearance of a highly vesicular basic lava.



Another well-marked vesicular variety occurs as a narrow bed associated with the calcareous pebble-bed two miles south of Portsonachan. A section shows fairly numerous amygdules, filled with calcite, and mostly more or less drawn out. The main mass of the rock consists of larger and smaller lath-shaped plagioclases, unorientated, grains of iron-ore, some greenish alteration products, and interstitial matter. The structure is that of a very fine-grained dolerite or basalt.

We thus have varieties of the so-called "epidiorites," which in hand specimens and in thin slices under the microscope are strongly suggestive of true lavas, and similar rocks have been mapped in Sheet 37 to the south, and are described in the explanation of that sheet. (See also Summary of Progress of Geological Survey for 1900, p. 42, also for 1899, p. 62.) Some of these vesicular rocks resemble the Lower Silurian lavas associated with the radiolarian cherts of the Southern Uplands, but there is no field evidence in support of this view in Argyllshire. On the contrary, the evidence has always hitherto tended in a contrary direction, and has shown, in most cases conclusively, that the "epidiorites" are intrusive sill-like masses.

In the area further east, about the head of Glen Shira and between Glen Shira and the lower part of Glen Orchy, the sills belonging to this series are usually of the common schistose epidiorite type, though slight variations are common and porphyritic types are often characteristic. Vesicular varieties do not occur in this area. On the east side of Glen Shira and over the high ground about Beinn Bhuidhe a coarse type of epidiorite occurs showing scarcely any signs of foliation, and containing comparatively large aggregates of green hornblende.

To the north of this area, as we enter Glen Orchy or traverse the high ground on the north side of the Strath of Orchy, we find that the epidiorites have been mostly converted into hornblende-schists, owing to their being situated in a more highly metamorphosed area. They consist usually of fresh green hornblende and plagioclase felspar, with a varying proportion of biotite, and occasionally a small quantity of granular quartz [5527]. Some of the sills also contain numerous small garnets. About two miles to the south-west of Dalmally a large sill occurs, which for the most part consists of the normal type of chloritic schist, but in parts shows a considerable amount of variation. It is often very felspathic, and in one place, about a mile west of the Monument on the road between Dalmally and Cladich, exhibits a modification which is practically an acid biotite-gneiss. A section of the rock shows the following composition and structure under the microscope [9611]:—Orthoclase, plagioclase, and microcline are present in larger masses, which have sometimes, though not often, traces of crystalline form, and in smaller grains of imperfect shape. Quartz in considerable amount mingled with the smaller felspars to form a granular or interlocking mosaic. Fresh brown biotite is seen in small

interwoven plates disposed in well-defined curving lenticular folia; epidote, in well-shaped crystals and small rounded grains, scattered through the micas and feldspars; magnetite, apatite, zircon. Apparently there is no hornblende nor sphene, but brown and greenish hornblende have been observed in other parts of the mass [5685]. The rock was probably originally a porphyritic granite, and has been to a large extent reconstructed. The structure is that of a gneiss. Muscovite and calcite are present, though not abundant. Micropegmatite also sometimes occurs [5684, 5519], and the effects of strain and mechanical ruptures are well shown.

In the north-east corner of the map a peculiar rock occurs to the south of Clais-gobhair, referred to in the previous chapter, which may be provisionally classed with the epidiorites. A similar rock has been mapped in Sheet 46 to the east at about the same horizon. It is a greenish schist or gneiss, and appears to consist of a complex containing hornblendic, epidotic, and pyroxenic gneisses, sometimes with sphene, while some portions have a large proportion of calcareous matter.

The sills of the Pass of Brander area frequently show the effects of the contact action of the Ben Cruachan granite, and these will be described in the section dealing with that subject.

In the area to the north-east of Glen Salach intrusions of epidiorite are not nearly so numerous as in the Loch Awe area. They are very seldom of large size, and frequently only a few feet in breadth. Between the head of Loch Creran and the margin of the Ben Cruachan granite they become still less common, and frequently appear to behave rather as dykes than sills. The original rocks of some of these dyke-like intrusions were probably closely allied to porphyrites. They have been altered by the Ben Cruachan granite, and will be referred to again in a later section.

ii. *Contact Metamorphism*.—Along the margin of the sills of epidiorite, chlorite-schist, &c., described above, where they are in contact with the schists of sedimentary origin, the latter have usually undergone a certain amount of contact alteration, but it is only in cases where the schists consist of rocks especially susceptible to such alteration, such as impure limestones, that this phenomenon has been remarked to any great degree. In the Kilchrenan district, where the older igneous masses are often of considerable size, they frequently occur in contact with bands of limestone and impure calcareous rocks. The purer bands are often converted into a pale highly-crystalline limestone, or marble, while the less pure rocks become hard and hornstone-like, assuming rather the condition of hornfels. To the east of Kilchrenan and to the south-west of Achnamady, in the same district, compact, cream-coloured, hornstone-like rocks are seen in contact with the epidiorites. These rocks apparently belong to the limestone series, but they are so siliceous that they were probably originally bands of siliceous limestone, though to a certain extent there may have been a replacement of carbonate

by silica. Under the microscope the constituents of the rocks are often too small for precise identification, but they appear to consist mainly of colourless quartz and felspar and granular pyroxene or epidote, and some carbonate still remains [7633, 7634].

No contact alteration of any very marked degree has been noticed in connection with the black schists or the quartzites.

H. K.

## CHAPTER VI.

### FOLDING AND PROGRESSIVE REGIONAL METAMORPHISM.

The metamorphic rocks that fall within this sheet are almost entirely restricted to the eastern portion of the map, being cut off to the westward by the Ben Cruachan granite and the Lower Old Red volcanic rocks of Lorne and Benderloch. In the north-western portion of the map a smaller area of metamorphic rocks lies in the district about Loch Creran and that part of the island of Lismore which is included in this sheet. The eastern area falls naturally into two districts, one of which, forming the basin of Loch Awe, is comparatively low-lying, while the country extending beyond those limits is elevated and mountainous. A line following the course of the Pass of Brander, the upper part of Loch Awe, Strath Orchy, and from thence curving round to Glen Shira, approximately defines the limits of these divisions. These areas, however, are not only marked by a distinct topography, but the rocks which they contain represent degrees of metamorphism equally divergent. While in the Loch Awe basin are found some of the least-altered rocks that are known in the Highlands, the mountainous region which borders it is made up of crystalline schists of the normal type that enters into the composition of the South-East Highlands. These extreme metamorphic distinctions within such narrow geographical limits, and the progressive gradations which link them, are of the greatest interest in elucidating the genesis of the crystalline schists. Their study has enabled us to demonstrate\* that a great group of rocks which traverse the Highlands in the condition of typical crystalline schists pass along their strike into sediments practically devoid of crystallisation, the lithological characters of which are equivalent to many Palæozoic deposits.

The sediments lying within the Loch Awe basin embrace the Ardrishaig and the Loch Awe groups. Both these groups pass into the metamorphic area. The latter group enters largely into the geology of the Strath of Orchy and the mountainous area lying to the north of that strath. The Ardrishaig group does not occur in that northern area, but its metamorphic type occupies the mountainous tract between the slopes of Beinn Laoigh and Glen Shira. To the east of that group the garnetiferous mica schists, the Loch Tay limestone, green beds, and albite schists are all confined to the area of advanced metamorphism.

Epidiorites and associated intrusions of Dalradian age are a marked feature in the less-altered area of the Loch Awe basin.

\* J. B. Hill on the Progressive Metamorphism of some Dalradian Sediments in the Region of Loch Awe. *Quart. Jour. Geol. Soc.*, vol. lv., p. 470, 1899.



In the metamorphic districts they are more rare, but are of more common distribution in the region south of Strath Orchy than north of that line.

Besides these Dalradian intrusions, the metamorphic area has been invaded by the granite masses of Ben Cruachan and Glen Fyne. The tract between these plutonic masses in this sheet constitutes the metamorphic area. Moreover, smaller bosses of granite and kentalenite are seen in the intervening ground, and it is possible that these schists are underlain by a connected belt of plutonic rock. The regional metamorphism of the area is associated, therefore, to some extent with thermal metamorphism, and where the rocks have been subjected to both types of alteration it is not always possible to differentiate their respective limits.

Perhaps the least-altered rocks are those on the western side of Loch Awe between Kilchrenan and the Pass of Brander. The Ardrishaig phyllites of that area are practically in the condition of clay slates. In Chapter IV. these rocks have been described from their unaltered condition on Loch Awe, through their various stages of increasing metamorphism, until they finally culminate on the flanks of Beinn Bhuidhe as typical crystalline schists. Moreover, the Loch Awe group with which they are associated south of the Pass of Brander is in a similar unaltered condition. The black schist which is here typically developed occurs mostly as black slate, which has been quarried for roofing purposes. The cleavage-dip does not usually exceed  $45^{\circ}$ , and the original bedding planes are often very clear and frequently lying almost horizontal. Moreover, they show a much smaller amount of puckering than in the more metamorphosed beds east of Loch Awe. The folding of the whole group is isoclinal and shallow, so that there is a considerable reduplication of the strata. The limestone is frequently very impure and often intermixed with black slate and Ardrishaig phyllites; these alternating bands bring out very clearly the plication. The limestone is often of the pebbly type. The quartzite in this area is mainly in the condition of a grit which has suffered very little from shearing, but it is occasionally well cleaved. It frequently contains inclusions of black slate, and is often divided by partings of that material. The clastic grains of quartz and felspar are practically uninjured even when the rock is cleaved.

Traced in a northerly direction towards the Pass of Brander, both the Ardrishaig and Loch Awe groups have suffered contact metamorphism by the Cruachan granite. This is mainly shown in the impure limestones, not only by their induration but by the development of calc-silicates, the production of epidote having induced yellow and green colorations to the rock. Further, this metamorphism more markedly differentiates the calcareous and phyllitic alternations by which the rock is strongly banded, the argillaceous material being of a purple colour in striking contrast to the green and yellow calcareous bands. The alterations of those rocks on the north side of the Pass of Brander will be dealt with later.

The eastern extension of the Loch Awe group between Loch Awe and Glen Shira shows a gradual increase in metamorphism. This is most clearly seen in the grits and quartzites which occupy the elevated tract between Acurragh and Glen Shira. To the west of Beinn Ghlas very massive quartzose beds alternate with coarse grit bands, both being highly folded, while the finer grit bands are much sheared. To the east of that hill the coarse grit bands have been sheared, and even the larger pebbles flattened and elongated. Nowhere, however, in this area has deformation proceeded so far as to destroy the clastic structures. This group can be followed no further to the eastward on account of the compound fold previously referred to. Progressive metamorphism is from thence represented in the Ardrishaig group. These phyllites at the head of Glen Shira are already in the condition of crystalline schists, and their eastward extension from thence to Beinn Bhuidhe shows an advancing type of crystallisation. This increase in crystallisation, however, although an important feature, is not of the same interest as the tracing of the group from Loch Awe to Beinn Laoigh. The latter shows the complete passage from unaltered rocks into highly crystalline schists; the former records only progressive metamorphism from one stage of crystallisation to another.

This tract eastward of Glen Shira is confined to steep mountainous slopes that culminate in the peaks of Beinn Bhuidhe and Ceann Garbh. The Ardrishaig phyllites along this ridge not only become more coarsely crystalline, with plates of chlorite and white mica conspicuously differentiated, but this advanced state of crystallisation is accompanied by marked induration, so that the rocks, instead of being easily disintegrated, resist weathering to such a degree as to form precipitous crags. In these highly-altered beds small garnets are sometimes developed. Moreover, these features of crystallisation and induration are accompanied by a most intense type of plication that not only produces a gnarled structure in the field, but the convolutions are so rapid and irregular that the dip as regards both bedding and foliation is never constant. This intense plication is well brought out on the map by the irregular outlines of the epidiorite sills in the neighbourhood of Ceann Garbh.

Not only are the eastern limits of the Ardrishaig group from the slopes of Beinn Laoigh to the ridge of Beinn Bhuidhe in a highly metamorphic condition, but the schistose groups between that group and the eastern portion of the map are likewise in an advanced stage of metamorphism. These groups include the garnetiferous mica-schists, Loch Tay limestone, green beds, and albite-schists; they occupy the slopes of Glen Fyne, and, as regards the first group, the slopes of Beinn Laoigh also. They exhibit a high degree of gnarling and contortion, and have been so completely deformed that clastic structures have often been entirely destroyed. Moreover, in addition to mineral reconstruction, certain secondary minerals, such as garnet,

actinolite, and albite, have been so extensively developed as to impress distinctive characters along stratigraphical horizons. The gritty sediments that are represented in these groups now consist of biotite gneisses, in which granulitic aggregates of quartz and felspar are separated by folia rich in mica. Phacoids of quartz and felspar are commonly broken up into lenticular granulitic aggregates with tail-shaped terminations. Moreover, the mosaic of the phacoids often blends with that of the faser matrix. In addition transverse structures have been induced by secondary planes of schistosity, and these banded gneisses are frequently puckered and gnarled. The phacoids are usually the sole indication of the original clastic structure, and in the absence of these grains all traces of such elastic conditions are obliterated.

But, in addition to the destruction of the original constituents of the rock, the authigenic minerals include garnet, actinolite, and albite of a later generation. The garnets are extensively developed in the garnetiferous mica-schist group, but are not rigidly confined to that horizon. They are sparingly distributed in that part of the Ardrishaig series which adjoins this group when the former are in an advanced stage of metamorphism. Moreover, they are occasionally seen as small pale grains in the limestones, and they also occur at times in the bands immediately below the limestone, including the green beds. In some bands garnets account for a large proportion of the rock. Although usually idiomorphic they are frequently fractured and foliation planes tail round them. Moreover, they are often represented by pseudomorphs of chlorite, and these latter frequently form lenticles that tail at their extremities parallel with the foliation planes.

Actinolite is of less frequent occurrence, and is not confined to the garnetiferous group, but is equally abundant in the albite-bearing schists. Although this mineral has also been often replaced by chlorite, it does not appear to have been deformed. In some cases, however, the chloritic pseudomorphs after actinolite have been penetrated by garnets, so that although the production of these minerals is not restricted to identical periods, it is probable that they overlap one another.

The secondary albite which occurs in tiny crystals in the schists below the green beds are also found in the latter zone. This mineral appears to play the same role as the garnets do on another stratigraphical horizon. Unlike the garnets, however, they exhibit no mechanical change. Considering them, therefore, as groups, albite is of later introduction than garnet.

The high degree of metamorphism in this area is no less marked in the Green Bed group. While to the south of this sheet the elastic nature of these rocks is apparent, in the Glen Fyne area the allothigenic constituents have disappeared. Moreover, actinolite has taken the place of chlorite, and these rocks are now represented by hornblendic schists the structure of which is indistinguishable from that of igneous rocks. Seeing the



advanced state of metamorphism that the schistose groups on the south-eastern portion of the sheet exhibit, it is not to be expected that progressive metamorphism should be marked. Nevertheless their northern prolongation shows a coarser type of crystallisation, both as regards the micaceous and chloritic minerals and the accessory minerals, garnet and actinolite, which are of a later generation,

*North of Loch Awe.*—Having described the metamorphism of the area south of Loch Awe and the Pass of Brander, the region to the north will now be dealt with. This district includes a narrow strip between the Pass of Brander and the Cruachan granite, which expands at the head of Loch Awe into an extensive region between that granite and the eastern margin of the map, and extending southward as far as Strath Orchy and Glen Lochy.

That undulating line from the Pass of Brander to Glen Lochy not only demarcates areas of distinct types of metamorphism, but also marks the southern limits of the Grampians. The mountainous region to the north, instead of showing a gradual declivity towards the less elevated tract forming the Loch Awe basin, terminates abruptly as a mountainous barrier. This sharp topographical change is the result of an equally sharp contrast in the metamorphic action that marks these respective areas. It will be shown that the lithological types of the mountainous region to the north are the equivalents of the rock types further to the south, but in an altered condition. So much is this the case that it is probable that the northern area is almost restricted to the Loch Awe group itself. As the Ardrishaig phyllites in their passage to the east, instead of retaining their extremely soft character, have built up the rugged chain defined by the peaks of Beinn Bhuidhe and Ceann Garbh, so the Loch Awe group which is so largely developed in the basin of Loch Awe have in their northern extension given rise to the wide mountainous tract extending to the Black Mount.

The marginal zone between those tracts occupies the east and west basin of the lower portions of the River Orchy and of the River Lochy. Along the southern side of that basin the Ardrishaig phyllites have been traced, and with an increasing metamorphism from the west to the east.

*Strath Orchy Area.*—In this Strath Orchy area the Ardrishaig phyllites are succeeded normally to the north by the Loch Awe group, in which the black-schist division is strongly represented due to repeated folding. The succession is especially clearly seen in the Allt Aindrea burn below Ra Chreag, where the limestone is interposed between the Ardrishaig phyllites and the black schists. The limestone adjacent to the Ardrishaig phyllites is made up of thin beds, greyish-white to brown in colour, which seldom reach the thickness of a foot, separated by partings of Ardrishaig phyllite. As the top of the band is approached the limestone is of a cherty nature, and is dark in colour, and is there associated with dark slates of Loch Awe type. For upwards of a quarter of a mile along the burn and across the



strike the section is made up of sharp alternations of black slate and limestone too closely folded to admit of differentiation. This close inter-association of dark slate and limestone is the predominant type in the Strath Orchy area, so that masses of pure limestone are comparatively rare. This character is important in its bearing on the more metamorphic region to the north. The burns further west which drain into the Orchy afford similar sections, but the limestone is not so well exposed. The black schists are intermixed with paler argillaceous material, as is usual in the Loch Awe group. Not only so, but these dark schists are often more siliceous and intermediate in character between quartzose and argillaceous rocks. Moreover, they are closely interbanded with thin quartzites and less siliceous bands, some of the latter being dark in colour. In places where the quartzites are more strongly developed they are seen to be of the characteristic type of the Loch Awe group, in parts being made up of coarse grit. They contain also the pockets of dark slate so characteristic of the Loch Awe division, and are similarly divided by thin partings of dark slate. The gritty type of limestone is, however, only of exceptional occurrence. The Strath Orchy zone, therefore, is in reality an interfolded admixture of impure limestone, dark phyllite, and quartzites, but in which the dark phyllites are predominant. Moreover, all these members belong to the Loch Awe group, and the succession from that group to the Ardrishaig group conforms to the usual sequence.

The easterly prolongation of this group in Strath Orchy exhibits an increasing metamorphism corresponding to that of the adjacent Ardrishaig group already described. It may be stated at the outset, however, that the material of the dark slates do not yield so readily to the metamorphic agents as the softer Ardrishaig phyllites. This is possibly due to the graphite which enters into their composition. The easterly prolongation of the belt, therefore, from the Strath of Orchy is rather marked by a more massive and indurated condition than a coarser type of crystallisation. Moreover, the development of secondary minerals in increasing force along this belt is the principal characteristic in its progressive metamorphism.

The dark limestone near Dalmally is very impure. It contains minute crystalline grains of carbonate, irregular grains of quartz, very small specks of opaque matter, probably carbonaceous, and some fairly large cubes of pyrite [5202]. In the neighbourhood of Socach, where more metamorphosed, the limestone is represented by a calc-epidote-schist. It contains large irregular crystalline grains and aggregates of carbonate, lying in a foliated matrix. The former take on a lenticular character, and appear therefore as "augen" on the sliced surface of the rock. The schistose matrix is composed of quartz, epidote, and biotite, with which grains of carbonate are also associated. Typical calcite forms but a very small portion of the rock, and it is traversed by films rich in biotite [5210, 5518]. Moreover,

with the development of the calc-silicates the rock ceases to effervesce with cold dilute acid. (Plate III.)

The dark phyllites are also often rich in carbonates, and these calcareous phyllites grade into the impure limestones. About a mile east of Dalmally they occur as lead-coloured calcareous phyllites containing some narrow coarser bands and lenticular folia rich in magnetic pyrites. Under the microscope the principal constituent is seen to be a carbonate, which does not effervesce with cold dilute acid. The other constituents are quartz, opaque grains and particles, probably graphite, some indeterminable minerals and tourmaline in scattered idiomorphic prisms [5203]. Brown mica is also present in the rock. Some of the graphitic schists in the same locality contain calcite [5205], and in the River Lochy,  $2\frac{1}{2}$  miles east of Dalmally, the calcareous graphitic schists are of the same type. In the same river half a mile east of Inverlochy these rocks are coarser in texture. A typical dark schist from the neighbourhood of Inverlochy shows under the microscope opaque grains scattered through the mass of the rock, which is of very fine grain. The two principal constituents are quartz and white mica as in many phyllites. In addition there are two conspicuous minerals, brown mica and chloritoid. The former is comparatively free from inclusions, and shows a marked tendency to lie with its flat surfaces approximately parallel with the schistosity. The latter is often full of inclusions of opaque particles, which run through it in lines approximately parallel with the general foliation of the schist; on the other hand, the flat surfaces of the mineral lie right across the general foliation, thus proving that growth took place after the cleavage had been produced [5204].

At Inverlochy and further eastward along the River Lochy garnets and actinolite appear, the latter in blades sometimes decomposed to chlorite. The dark schists are here more massive and are often very rich in actinolite and garnet. About a quarter of a mile east of Inverlochy the garnets increase in size, and there are small zones in which this mineral is thickly distributed, and in which they exceed half an inch in size. Moreover, some of the garnets have been crushed and form eyes with the foliation tailing round them. In this same locality some of the limestones are gritty, and the coarse grits of Loch Awe type are seen enclosing lenticles of dark leaden schist corresponding to the clay slate pockets seen in less-altered areas. These rocks, however, have been so altered that the pockets are flattened out, and the clastic grits no longer project on the weathered surfaces of the rock. Moreover, the rock when fractured behaves as a homogeneous mass and cuts across the clastic grains, which are not only partially granulitised but elongated and flattened.

*Northern Area.*—The mountainous slopes that rise to the north from the Strath of Orchy and Glen Lochy consist of the same assemblage of rocks as have been described in the latter, but the siliceous members predominate. Moreover, the metamorphism has advanced a stage further, so that the maximum crystallisa-

tion pertaining to the latter belt probably represents the minimum metamorphism of the northern area. Among the quartzose rocks both black and white mica have been abundantly developed. They have become granulitised, and by recrystallisation pass over in their extreme phases of metamorphism into gneisses. But notwithstanding this alteration the coarser grit can still be detected; although the larger pebbles are flattened, pulled out, and crushed, the alternations in bedding of coarse and fine bands can be seen, and the coarser conglomeratic zones occurring in the less-altered beds of the Loch Awe basin are here represented. The black slate partings are also still recognised, but no longer in the condition of a slate, having been altered into a hard dark micaceous rock. The pockets of phyllite within the grit, so characteristic of the unaltered beds to the south, are still seen in these highly-altered quartzose beds. Like the slate partings, however, they have been converted into dull, lead-coloured, crystalline, micaceous material. The rocks no longer, in weathering, show the distinctive characters of hard and soft alternations, but the micaceous partings and the quartzite bands have, as it were, become welded into a solid homogeneous mass. The dark micaceous alternations, when the rock is in this condition, impart a banded structure and a bluish coloration to the mass. Moreover, the large quantity of secondary biotite which is scattered through both the quartzose and micaceous zones still further darkens them. These grits and quartzites have passed into rocks which are gneissose in character; the more siliceous, however, remain as quartzites and quartzite-schist.

Biotite, garnet, actinolite, tourmaline, and epidote are common as secondary minerals in this highly-altered area. The biotite has been one of the latest minerals to crystallise, and has been generally unmoved. It often occurs in long blades with somewhat ragged margins. The tourmaline may be of the same age, as they occur in long prisms, unbroken, some of which are half an inch in length. The garnets and actinolites attain considerable dimensions; the former occur as large as half an inch, and the latter are in blade-like forms sometimes an inch long. Although garnets and actinolites are widely distributed over this area, they are most closely concentrated in the more micaceous beds. In certain zones they are especially abundant; for instance, one bed was observed on the slope of Glen Orchy at Allt Odhar about 6 feet in width literally studded with garnets half an inch in size or even larger. In this case the foliation was clearly seen to curve round the garnets, which, besides being crushed, are often cleaved parallel to the foliation-planes of the rock. In most cases, however, that mineral is idiomorphic and shows no sign of deformation. In this instance the garnets form pebble-like patches that are partially granulitised, and in which there is a small amount of granular quartz. Moreover, the breaking down of the garnet has given rise to a reticulated network of chlorite which marks the initial stage of the pseudomorphous replacement of garnet by chlorite so commonly seen



over the garnetiferous zones generally. In this case the deformed garnet blends at its edges with the granulitic matrix just as the quartz phacoids do in the deformed grits. The schistose matrix consists of granulitic quartz and felspar, white mica, brown mica, iron-ores, and a ferriferous carbonate [5530].

The progressive metamorphism from the area of Strath Orchy into this mountainous district is well illustrated along the River Orchy between Corryghoil and Bochyle. Near Achanafaudich the beds exhibit a uniformly massive condition, and at first sight appear as a continuous succession of quartz-schists and quartzites. Some of these hard beds, however, are very micaceous and represent altered phyllites, and others are calcareous mica-schists that represent the impure limestones of Strath Orchy. The river section half a mile south of Bochyle exhibits a still higher degree of metamorphism, and these rocks are in the condition of banded gneisses of the Struan type. The banding has been brought about by the excess of biotite along alternations which probably mark bedding planes. But notwithstanding the large development of that mineral it occurs in tiny scales; nevertheless the dark slate alternations of Strath Orchy are here entirely crystallised and represented by biotite-schist, while the more sandy phyllites have been converted into biotite gneiss. At Bochyle there is a greater development of micaceous beds, which are in parts almost entirely made up of biotite. About half a mile north of that locality the quartzose beds are intermixed with much dark micaceous material. Moreover, these bluish micaceous zones are highly charged with garnets and actinolite, but these minerals have usually been altered into chlorite. These bluish schists are so highly garnetiferous as to recall the garnetiferous mica-schist group. The matrix, however, of the rock is not typical of the latter, and there can be little doubt that these rocks are the metamorphosed representatives of the Loch Awe phyllites. Under the microscope a specimen from this locality of one of these highly schistose rocks, intermediate in character between a phyllite and a garnetiferous mica-schist, and which consists of numerous garnets more or less converted into chlorite, and a phyllitic matrix, shows the following characters:—The principal constituents of the matrix are quartz and white mica, the individuals being somewhat larger than is usual in ordinary phyllites. In this matrix occur some large and more or less irregular individuals of brown mica and the garnets already referred to. The foliation-planes curve round the garnets [5208]. Here also the alternation of bands richer or poorer in biotite give the rock a striped gneissose character, and when these two are sufficiently intermixed the coarse banding disappears and the rock appears as a uniform bluish gneiss. A little to the north a large exposure of the dark biotite-schist is seen representing an infold of the metamorphosed black phyllites free from quartzose intercalations. Between this black schist and Larig a true quartzite is seen. This rock has a highly baked appearance. It is not only intensely hard,



but is almost white in colour, and resembles a rock that has been almost completely resilicified, and so much is this the case that it closely resembles the quartz segregations into which it almost appears to blend. The original foliation-planes are very faint, and in some cases are getting obliterated; they are more conspicuous, however, on the weathered surfaces. On the whole the appearance in the field is very suggestive of a rock that has been subjected to a high degree of thermo-metamorphism. A little further up the burn, where this highly siliceous character has disappeared, small pegmatite veins are common. In many cases these segregations are made up entirely of red felspar, which occurs as a coating or skin along planes of fracture and joint faces. It also borders the outer edges of quartz veins. Where it coats a joint face, the adjacent rock for a short distance is also impregnated with this red felspar, so much so as to itself take on a pegmatitic appearance, but with the schistose structures still remaining.

The mountainous region between Glen Orchy and Glen Strae presents similar lithological types to those described in Glen Orchy. As a rule, the beds have been so welded and indurated that neither the intense plication of the rocks nor the original bedding planes affect the general weathering. In some cases, indeed, both these earlier structures have been almost entirely obliterated. In the neighbourhood of Beinn Donachain, however, some thin micaceous schists reveal the intensity of the contortion. Garnets and actinolites of large size are abundantly distributed in the more micaceous and calcareous zones, but are absent in those more purely siliceous. The limestone bands are represented by calcareous schists that are often chloritic. An extreme phase of the alteration of one of these impure limestones is seen half a mile south of Beinn Donachain. Here large blades of black hornblende are closely packed in a schistose matrix consisting of white mica, brown mica, felspar, quartz, epidote, rutile, and a ferriferous carbonate [5531]. At Na Cailleachan a considerable tract of quartz-schist and mica-schist exhibits such extreme alteration that the more siliceous portions have been converted practically into a solid mass of quartz in which the bedding planes have been preserved. The more micaceous portions have a baked appearance, the mica is very coarse, and garnets and actinolites are abundant. An adjoining zone is made up of quartzose beds, in which red pegmatites are seen similar to those in Glen Orchy.

West of Glen Strae the quartzose-schists are charged with red felspar grains to such an extent as to give a pinkish hue to the crags extending along that hillside. Moreover, red felspar veins are common similar to those described in Glen Orchy. It not only occurs as veins and strings along joint planes, but also along foliation-planes, and in these latter the felspar increases in amount as a joint plane is approached. While there is no doubt that so far as these veins and strings are concerned the felspar is secondary, in the case of the isolated grains of similar material

in their contiguity we have no criterion to decide how far they may be secondary or to what extent they represent clastic grains. It is probable, however, that both these conditions are represented. That these red felspathic strings, however, are bound up with the metamorphism of the area is demonstrated by the fact that they are confined to this metamorphic area, notwithstanding that the same rock bands of identical composition enter largely into the geology of the less metamorphosed district.

*Metamorphism of the Igneous Rocks.*—Having described the progressive metamorphism of the sedimentary bands that radiate to the north and east from the comparatively unaltered focus south of the Pass of Brander, the corresponding metamorphic changes which have been induced on the Dalradian intrusives will now be briefly touched upon. These rocks, although presenting wide variations in their composition, have been grouped for convenience with the family of epidiorites. Strictly speaking, however, they contain types that, as regards both composition and structure, extend beyond the petrological limits of that group. They are likewise unevenly distributed over the area. Although in the Loch Awe basin they are profusely developed, they show a marked diminution towards the east; while in the northern region to the north of Strath Orchy they are still more sparingly distributed. Owing to the isoclinal folding of the district these rocks are exposed at the surface as isolated masses, and consequently the progressive stages in the metamorphism across single intrusions cannot be continuously traced. In spite, however, of this lack of continuity, the metamorphic character of these rocks bears a definite relation to the crystalline condition of the schists amongst which they occur.

Beginning with the unaltered area lying between the western side of Loch Awe and the Pass of Brander, these intrusions are no more altered than the greenstones of Cornwall that have been intruded in the killas of that region. Many of them are doleritic in structure, the original felspars are largely unaltered, and the augite is now represented by uralitic hornblende, and in some cases seems to be represented by pseudomorphous products. A feature in these rocks of the Kilchrenan area is the occurrence of biotite similar to the development of that mineral in areas of contact metamorphism. This character still further links them with the Cornish dolerites in areas of contact metamorphism. In the Kilchrenan district, however, the Ben Cruachan granite is too far distant to have produced contact action on these rocks. The presence of this mineral, therefore, in association with the early stages of the deformation of these intrusives indicates thermometamorphism, and attention has already been drawn to the regional metamorphism of the region immediately to the north-east being of a thermal type.

From Loch Awe to the mountainous area of Beinn Bhuidhe these intrusives are abundantly distributed, but as the latter area is approached have undergone an increasing metamorphism corresponding to that of the sediments with which they are

associated. The doleritic structures have been obliterated, and, except as regards the porphyritic feldspars, the original minerals have been completely replaced. Except the very coarsely crystalline types, the rocks have been completely foliated, and consist of epidiorites, hornblende and chloritic schists. Moreover, the porphyritic feldspars so abundant in the basic andesitic varieties of Loch Awe have here suffered much deformation. Small garnets are also an exceptional feature, while in the neighbourhood of Socach they contain white mica.

In the highly metamorphosed area between Glen Strae and Glen Orchy these Dalradian intrusives have undergone great alteration. They have been considerably granulitised and their recrystallisation is almost complete. The hornblende is usually very dark in colour, and black actinolite is common. In this area chlorite, which is so common a feature in the epidiorites of the southern district, is absent, and if originally present has been converted into hornblende and biotite. Moreover, the porphyritic idiomorphic feldspars have been considerably granulitised, and are represented by irregular blotches. The epidiorites of this northern area are hard and compact, and, like the schists with which they are associated, decompose less readily than the rocks of the area south of Glen Orchy.

The peculiar type of metamorphism of this northern area is one associated with intense induration, and the rock bands have the appearance of having been acted on by a regional type of thermo-metamorphism. Moreover, this alteration represents the last phase in their history. For not only has the final crystallisation of the area been unmodified, but the red feldspar veins have occupied the later joints, and finally the pre-existing fault fractures have shared in that metamorphism, and their breccias have been welded as a solid mass in common with the enclosing rock. As stated earlier, these rocks bear a strong resemblance to those of Struan, consisting of flaggy granulitic gneisses and mica-schists.

The westerly extension of this northern area along the Pass of Brander has not been touched upon in this chapter, as that strip almost entirely falls within the contact aureole of the Cruachan granite, a description of which will be given in Chapter X.

J. B. H.

In the districts of Appin, Benderloch, Lismore, and Oban the rocks, though much folded and cleaved, are otherwise comparatively unaltered except near the granite masses. Evidence of crushing and brecciation of the metamorphic rocks of the same general age as the plication is presented at several localities, and notably in Benderloch round the shores of Ardmucknish Bay. Perhaps the most remarkable example is the crush conglomerate of Port Selma, which has been carefully studied by Dr. Flett.

On the shore below the Beregonium, about three hundred yards west of Benderloch Railway Station, there is a very fine exposure of crush conglomerate. The importance of rocks of this class in



Argyllshire was first insisted on by Mr. J. B. Hill,\* who found them in the Loch Awe and Kilmartin districts. Few better instances than that about to be described could be adduced in any part of the county. Lying on the sea shore, where the rocks are scoured by the shifting gravels of Ardmucknish Bay, it exhibits very clearly the manner in which a mixed series of rocks can be broken up by movement and converted into a conglomerate which closely simulates a true boulder bed.

The semicircular sweep of the east side of the bay is interrupted at this point by a promontory composed of bare rock rising through the sands and forming the west end of the small hill on which the Beregonium stands. On the north side, near the crofts of Selma, a shining calcareous black schist is the principal rock. Followed southwards it gives place to a dark graphitic limestone, which has the characters of the Easdale limestone of Argyllshire. The foliation is nearly vertical and strikes about north-east, almost at right angles to the shore line.

On the south edge of the limestone the conglomerate comes in; the junction is very sharp, and the limestone is free from brecciation at its margin. There are no calcareous blocks in the conglomerate at this point. The limestone, however, contains lumps of a grey or brownish quartzite, from a few inches up to twelve feet in length. The smaller blocks are well rounded, but some of the larger are not more than eight inches thick, and show a tendency to subdivide into smaller pillow-like masses. All the quartzite is of the same character. Clearly these blocks represent bands of quartzite which have been dragged apart and rounded by the flow of the more plastic limestone matrix around them. They resemble the fragments of epidiorite in limestone described by Mr Hill† as occurring near the head of Loch Craignish. The amount of interstitial movement which their shape and relations to one another prove to have taken place in the limestone is far more considerable than might have been suspected from the appearance of the limestone itself.

From this point the crush conglomerate occupies the shore for a distance of about forty yards, and finally is lost under the sand and gravel of the south part of Ardmucknish Bay. Its appearance may be inferred from the photographs (Plate IV., figs. 1 and 2). The blocks are of all sizes, some being six to twelve feet long, but the majority are not over a foot in diameter. Very commonly they are of ovoid shape with rounded surfaces, and might be mistaken, if the exposure was less satisfactory, for clastic boulders. Others, however, are cuboidal with squared ends, while many of the softer rocks are flattened and lenticular. They are principally a grey or brownish impure grit or quartzite, like that above-mentioned as occurring in the limestone. The

\* Hill, J. B.—“On Crush-Conglomerates from Argyllshire,” *Quart. Jour. Geol. Soc.*, vol. lvii., p. 313 (1901). *Memoirs of the Geological Survey*—“The Geology of Mid-Argyll,” by J. B. Hill and others, p. 123 (1905).

† Hill, J. B.—“On the Crush-Conglomerates of Argyllshire,” *Quart. Jour. Geol. Soc.*, vol. lvii., p. 321 (1901).



largest blocks are mostly of this nature. Limestones are few except near the south edge of the outcrop, where many rounded lumps of this rock, about a foot in diameter, are scattered through the conglomerate. They weather with a brown crust, and do not exactly resemble the massive limestone on the north of the boulder-bed.

A few large pieces of black or grey shale are present, usually much drawn out, but a more common type of boulder consists of an alternation of thin bands of grey shale with yellowish fine grits. Large fragments of this rock occur, though less frequent than those of quartzite, and this would awaken suspicion as to the nature of the conglomerate, seeing that they are not adapted to form large boulders, but would split up if pounded by waves or currents. These boulders have often an internal brecciation, and can be traced passing, by various intermediate stages, through contortion into brecciation, and finally into conglomerates little less perfect than that which surrounds them.

The matrix of the conglomerate is a grey, sandy, and shaly rock with varying composition from point to point, but not, as a rule, calcareous. It shows a foliation or banding parallel to the strike of the limestone and black schist, and the blocks are usually arranged with their long axes in this direction. The simulation of bedding is, in consequence, often very perfect. The ingredients of the matrix are by no means very thoroughly mixed, but flakes and patches of grey shale, dark shale, and gritty shale lie in a slightly different ground-mass. These are usually thin and lenticular, and give the conglomerate a speckled appearance which is very suggestive of differential internal movement. The impression produced by an examination of this matrix is that it might have arisen from the mashing of a series of grey and black shales containing thin seams of more quartzose character. Much of the arenaceous material may have been derived from the attrition of the larger gritty blocks, which, to judge by their rounded shape, must have been considerable.

The especial merit of this exposure, however, is the clear manner in which the mode of formation of the rock can be established on the ground. On the north-west side of the outcrop, just below high-tide mark and adjoining the limestone, there is a mass of gritty and shaly beds about twenty feet in length. It is partly covered by the beach sands, but around it a belt of conglomerate or breccia can be traced as far as the exposure continues. In this mass there are strong quartzite bands, a foot or more in thickness, with alternations of grey and blackish shale or phyllite. The bedding as a whole is well preserved, and in the greater part of the mass there is little internal brecciation, but on the east side it can be seen to pass gradually into the surrounding conglomerate; the grit bands become bent and dragged apart; the soft shale flows into the gaps. Movement in the plastic phyllites produces a substance exactly like the conglomerate matrix; the grits yield boulders

which become more and more rounded as they are swept away in the moving shales. All the ingredients of the conglomerate at this spot can be matched in the unbroken beds.

Small inliers showing the same structures occur sprinkled through the crush conglomerate, and might be taken for large boulders, or, when they are more crushed, for brecciated patches of interbedded sediment. On the east side of the exposure, partly covered by the grass of the bank above the shore, there are larger masses of folded grits and phyllites, and here the phenomena are all repeated. With the exception of the brown-weathering limestone, all the rocks which are found in the conglomerate occur in these masses. At the junction between the conglomerate and the non-brecciated beds transition stages are very frequent. In places, also, the bedded quartzite and phyllite series is broken up, and resembles the less highly developed portions of the crush conglomerate.

The most conclusive evidence that a rock is a crush conglomerate, and not a boulder bed due to local erosion, is the presence of fragments of the overlying rocks. This cannot be demonstrated here, as on the south side no massive rocks are seen owing to the sand and gravel which obscure the section. There is, however, no room for doubt as to the nature of this conglomerate, as the stages of its formation are so perfectly exemplified and the very large size of the boulders, together with the fact that many of them consist of weak and friable rocks, preclude the hypothesis that they were detached from the parent beds and reduced to rounded shapes by the processes of sub-aerial erosion.

J. S. F.

## CHAPTER VII.

### LOWER OLD RED SANDSTONE.

#### *i. Distribution, Order of Succession, and Field Relations.—*

A very large area of the present sheet is covered by strata of Lower Old Red Sandstone age. These consist mainly of volcanic rocks, only a very small proportion of the area being occupied by beds of sedimentary origin. The volcanic rocks occupy almost the entire south-western quarter of the map, extending from the southern shores of Loch Etive, west of Bonawe, to the southern margin of the map west of Loch Awe, and from the south-western margin of the map to the Pass of Brander. On the north side of Loch Etive, they occupy the western portion of Benderloch, situated between Loch Creran and Loch Etive, and between the western slopes of Beinn Lora and Gleann Salach. The entire area is probably not far short of 110 square miles. To the west the Lower Old Red Sandstone volcanic area extends into Sheet 44, and reaches the shore of the Firth of Lorne to the south-west of Oban. On the south the volcanic rocks occupy a portion of the north-west corner of Sheet 37, and south-westwards they are continued into Sheet 36 as far as Loch Melfort. This extensive region is occupied by the Lorne volcanic series, formerly known as the Lorne "traps." The scenic features of this area are characteristic and distinctive, the monotonous succession of scarped and terraced hills, and the peat-covered moors with their numerous rounded knobs and bosses of rock, unrelieved by any conspicuous peak or lofty eminence, being in striking contrast to the steep slopes and bold contours of the granitic and metamorphic country to the east.

The rocks which occupy this area consist for the most part of lava flows of basic, intermediate, and occasionally acid composition, with their associated agglomerates and tuffs. At or near the base of this series we frequently find sedimentary rocks, consisting mainly of conglomerates, sandstones, shales, and mudstones, and similar intercalations, though generally of no great thickness, are frequently met with at various horizons amongst the volcanic outpourings. The sediments are apparently not always continuous, and vary considerably in thickness from place to place. They would seem rather to be of a local character, and indicate aqueous conditions of no very great depth or extent.

If we traverse the Lower Old Red Sandstone area from Oban in a more or less easterly direction, we should pass over the sedimentary and volcanic series in a generally ascending order. At the base of the series about Oban we find resting upon the

upturned and denuded edges of the black schists a series of coarse conglomerates, sometimes attaining a thickness of over 100 feet, and passing upwards into reddish and purple sandstones and shales. The conglomerates are well developed on the island of Kerrera, in Sheet 44, and to the north of Oban, and again form a fine feature beneath the andesites at Ledaig, on the east side of Ardmucknish Bay. Towards the south of Oban, however, they diminish in importance and decrease fairly rapidly in thickness.

The composition of these coarse, massive, rudely-stratified conglomerates suggests some reflections as to their source and formation. Though the conglomerates lie immediately upon the black schists, their component pebbles have only been to a trifling extent derived from this underlying platform. Around Oban, for example, the coarse conglomerates are to a large extent composed of pieces of andesitic lava. The most remarkable features of these pebbles are their frequent large size and well-rounded forms. Some of them must weigh nearly half a ton, and very considerable wave-action would seem to have been required to wear down these lava-blocks into their present shapes.

From the preponderance of andesite boulders in these detrital strata, it is obvious that there must have been large masses of this rock at the surface when the conglomerates were formed, and as the lavas of the Lorne plateau overlie all these basement conglomerates, it is equally certain that the volcanic phenomena did not commence with even the lowest lavas of that plateau. Lava-flows must evidently have been erupted before any of the visible conglomerates began to be formed. There may have been volcanic islands in the water-basin wherein the Lorne sedimentary series was deposited, and the destruction of these islands by denudation, with the consequent spreading out of their detritus as exceedingly coarse shingle over the rocky floor of black schists, might have given rise to the conglomerates. Some of the prominences of schist probably remained submerged during the accumulation of the lower sedimentary series, for on the south side of Loch Etive, a little to the east of Connel, Mr. Symes found the older rocks immediately surmounted by the lavas. The finer grits, flags, and purple shales, which intervene between the conglomerate and the base of the volcanic series, greatly resemble the ordinary strata of the Lower Old Red Sandstone of Central Scotland. Similar sediments continue to appear as occasional intercalations among the overlying lavas. Thus, on the west side of Connel Station, one of these partings consists of no more than eight inches of shale between two lava-flows, while in the immediate neighbourhood another sedimentary intercalation reaches a thickness of 50 feet, and is made up of shales and thin sandstones. It is thus evident that the detrital deposits continued during the successive outpourings of lava, and that the volcanic rocks were erupted, or at least flowed, under water.

To the east of Oban the observer traverses the lower series of



lava-flows. These consist almost invariably of basic andesites, often closely allied to basalts and sometimes closely resembling them in the field. When fresh these rocks are almost black in colour and often compact and very close-grained in texture, and without conspicuous phenocrysts. Porphyritic varieties, however, are not uncommon. The distinction between the different flows is often very clear, the upper portions being usually in a highly vesicular condition. These vesicles now constitute amygdules of calcite, agate, and other minerals. Occasionally the amygdules have been destroyed by weathering, and the rock has reassumed something of its original vesicular aspect. The upper surface of the flows is often in a slaggy and highly brecciated condition, showing numerous angular and sub-angular fragments of andesite in an andesitic matrix, doubtless the result of the breaking up of the consolidated upper layer of the flow by the still moving lower masses of lava. These lavas weather with a reddish-brown crust, while decomposition of the less compact varieties produces a purplish or sometimes almost brick-red rock by the destruction of the ferro-magnesian minerals and the oxidation of the iron-ores. Individual flows are often well defined, and form well-marked lines of crag and escarpment, which constitute so characteristic a feature of the hills of this area. Thus the slopes of Beinn Lora in Benderloch and of Deadh Choimhead on the north side of Glen Lonan exhibit this character in a marked degree.

Cracks filled up with fine sandy material are frequent all through these andesitic sheets, and are sometimes so numerous as to give the rock almost the appearance of a breccia. This phenomenon is in every respect similar to that observed so commonly among the lavas of Lower Old Red Sandstone age of other areas. The sandy silt has been washed into fissures and cavernous hollows of the cooled lava, and where these spaces have run along the middle of a single sheet they sometimes present a deceptive resemblance to ordinary sedimentary intercalations that separate distinct flows of lava.

Evidence of flow structure in the basic lavas may be often seen in the crags of the less decomposed varieties. Fine parallel ridges may be observed on the weathered surfaces, and the rock tends to split up into thin slabs or plates and sharp splintery fragments. This structure is well brought out in thin slices under the microscope, and will be referred to again in the section dealing with the petrology of the volcanic rocks.

Bands of fine red breccia, ash, or ashy grit are occasionally found interbedded with the flows; a good exposure may be seen among the basic andesites two miles S.S.W. of Connel Ferry. Xenoliths of quartz grains were found to be fairly common in these basic andesites in the western part of Benderloch near Ledaig, and at Airds Point, north-west of Bonawe.

Basic andesites of the above type form the lower portion of the series over practically the whole of the Lorne volcanic area. To the east of Oban one ascends over these basic sheets until one

reaches an horizon of tuff. This tuff is of an acid character, and is well seen  $1\frac{1}{2}$  miles east of Connel Ferry, and again at Airds Point, but it is better developed in the western portion of Benderloch, where it can be traced from Dubh Loch Beag round the western slopes of Beinn Lora, and thence in a general N.N.E. direction almost to the boundary of the volcanic series. Large masses of a somewhat similar tuff are again well seen in the Benderloch area further east, and on the south side of Loch Etive to the south of Achnacloich, in the area around the Sior Lochs, and on the east side of Glen Nant; but it is probable that these latter belong to a slightly higher horizon. Again, a thin band of tuff identical in character with that exposed  $1\frac{1}{2}$  miles east of Connel is found between basic andesites on the upper slopes and crags of Cruach Ard-dhuine,  $2\frac{1}{2}$  miles S.S.W. of Taynuilt.

The acid tuff, as seen near Connel Ferry, at Airds Point, and on the slopes of Beinn Lora, varies in colour from reddish purple to pale yellowish. It is often compact and flinty in texture, but more usually shows a strong flaky or platy structure, splitting easily into thin slabs parallel to the planes of bedding. The rock is frequently full of small lapilli of felsite and andesite, with here and there fragments of quartzite and mica-schist, while scattered throughout the matrix are small broken crystals of white, and sometimes glassy, felspar and flakes of biotite. Portions of the mass are often apparently entirely devoid of lapilli, and when this is the case the rock bears a very strong resemblance to a felsite. This tuff is well bedded, and in Benderloch and on Cruach Ard-dhuine forms well-marked lines of crag.

At a slightly higher horizon a massive crystal tuff occurs, which covers comparatively large areas in Benderloch to the east of the area occupied by the acid tuff above described. On the south side of the loch it has been traced in a S.S.W. direction from the railway cutting a short distance west of Achnacloich Station to the high ground overlooking Glen Lonan. Over part of this ground the tuff forms a striking feature in the landscape, the outcrop often terminating in an almost vertical wall of crag. In the railway cutting near Achnacloich and in the grounds to the south of the railway, this tuff has the appearance of a massive pink porphyritic rock, which might easily be taken for a felsite or felspar-porphry. It has a dull, compact matrix, throughout which are scattered abundant crystals of felspar and a smaller proportion of decomposed biotite. In places, however, the true pyroclastic nature of the rock is made evident by the abundant lapilli. Precisely similar tuffs occur in the area around the Sior Lochs, to the west and south-west of Loch Nant, and to the east of Glen Nant. These have been described by Mr. Kynaston in the Transactions of the Geological Society of Edinburgh, vol. viii., p. 87.

Immediately below these tuffs near Achnacloich, we find the normal type of basic andesite, while overlying them is a massive flow of porphyritic hypersthene-andesite, which extends from the ground south-east of Achnacloich to the high ground on the north

side of Glen Lonan. No beds of sedimentary origin have been observed associated with the above-described type of crystal-tuff. In connection, however, with the more acid type of tuff occurring on Cruach Ard-dhuine, S.S.W. of Taynuilt, beds of reddish shale, with sometimes sandstone and conglomerate, were frequently observed both above and below the pyroclastic rock. The acid tuffs are here from 30 to 40 feet in thickness. The more massive crystal-tuffs of Achnacloich probably have a maximum thickness of from 50 to 60 feet.

At about the same horizon as these latter tuffs, we find in the area between Achnacloich and Glen Nant a series of pale felsitic lavas, and these are again well developed in the area between Glen Nant and the Pass of Brander. To the north-west and west of Taynuilt these acid lavas are seen to underlie the massive series of porphyritic hypersthene-andesites, already referred to, and therefore to occupy here the same position that is occupied by the tuffs near Achnacloich.

These lavas have more the appearance of a felsite or rhyolite than an andesite. They are compact in texture, and vary in colour from purple to a pale yellowish or cream colour. As a rule, there is a well-marked banded structure due to flow, and small felspar crystals and occasionally flakes of biotite are distributed sparingly throughout the rock. The flow banding has frequently a uniform dip coinciding with the general dip of the series, but just as often it may lie at almost any angle from the horizontal to the vertical, or again it may show a folded and contorted appearance, caused by the movements in the original viscous mass of partially consolidated lava. Brecciation is also sometimes well seen, as, for instance, in the mass west of Gorstain, south-west of Taynuilt, which in certain parts consists of numerous angular felsitic fragments embedded in a felsitic base, showing fluxion-banding sweeping round the fragments. Spherulitic structures are also well exhibited, and are well seen in some of the exposures on the east side of Glen Nant. The usual appearance of these spherulitic varieties is that of numerous small nodules, of about the size of peas, crowded closely together in a felsitic matrix. Occasionally these nodules are as large as walnuts, and show hollow cavities in their centres. Associated with these felsitic lavas we usually find mica- and hornblende-andesites. These are well seen on both sides of Glen Nant in the neighbourhood of Tailor's Leap, where they apparently overlie the felsites. The crystal tuffs of the Glen Nant area succeed these acid lavas and hornblende-andesites.

Covering large portions of the high ground to the south-west of Taynuilt, about Carn Gaibhre, Beinn Ghlas, and the high ground further west, we have a considerable extent of mica-andesites, often more or less felsitic in texture. These possibly occupy the same horizon as those of Glen Nant, but it is difficult to say so with certainty.

These mica-andesites overlie a somewhat basic flow, and usually stand out in conspicuous crags, as at Creag-an-Fhithich,



$\frac{1}{2}$ -mile south of Carn Gaibhre. Fluxion-banding is often seen, but brecciation is perhaps more common, large masses of the rock having a thoroughly brecciated structure throughout, and showing numerous angular fragments of reddish, yellowish, and greenish felsite in a rather decomposed reddish matrix. Phenocrysts of felspar are occasionally seen, and small biotite flakes are very common. On Beinn Ghlas a porphyritic hypersthene-andesite rests immediately upon the mica-andesite, but further south-west, in the area about Lochan Dubha, other rocks appear to have been locally intercalated between these two. Thus we find here, resting upon the mica-andesite, a flow of very basic andesite closely resembling basalt, above which is a well-marked band of agglomerate and ashy material, succeeded by a purple porphyritic andesite, which is probably the same as that of Beinn Ghlas. The basic lava, resting upon the mica-andesite, is allied to basalt, and is often highly vesicular, the vesicles being represented by amygdulæ, often as large as hens' eggs, of reddish agate with usually an inner layer of crystalline quartz.

The agglomerate is well exposed on the north and west sides of Lochan Dubha, and forms the conspicuous crag of Creag Mhor, south-east of Kilbride in Glenfeochan, and it has been followed for some distance above the mica-andesites to the south of Clachadow in Glen Lonan. It consists almost entirely of fragments of different varieties of andesite in a finely fragmental ground-mass. They are occasionally more or less rounded, and often reach a diameter of 4 or 5 feet. Fine-grained ashy bands are associated with this coarse material. This fragmental band probably attains a thickness of about 50 feet, but it apparently represents quite a local outburst, as it has not been met with in other parts of the volcanic area.

Overlying the tuffs of Achnacloich and the felsitic lavas to the west of Taynuilt is the porphyritic hypersthene-andesite, already referred to. This occupies a considerable area between the upper part of Glen Lonan and the south side of Loch Etive. It is a dark purple, sometimes almost black, andesite with porphyritic crystals of plagioclase and greenish pseudomorphs after hypersthene. Flow structure is also sometimes seen. A very similar porphyritic lava occupies the upper part of Beinn Ghlas and overlies the mica-andesite, already described, and again a massive porphyritic flow covers all the upper portions of the hills between Kilbride, in Glenfeochan, and Loch Scamadale. Similar lavas appear again to the south of Loch Scamadale, and occupy the higher hills, such as Beinn Chapull and Beinn Dearg, to the east and north-east. These latter lavas evidently overlie the crystal tuffs, so well developed in that district, but are possibly at a higher horizon than those of Loch Scamadale. In fact, these upper flows of hypersthene-andesite are probably the highest lavas now seen in the Lorne area.

If we briefly review the general order of succession of the Lower Old Red Sandstone series of the Lorne area, we find that the lower portion of the series consists of conglomerates and local breccias



with shales and sandstones, followed by a series of basic andesites, often allied to basalt, and with these we occasionally find flows of less basic hypersthene-andesite. Ascending in the series we find acid tuffs intercalated with the basic flows, but followed at no great distance by another series of tuffs, perhaps somewhat less acid, with felsitic lavas and hornblende- and mica-andesites. These again are overlain by thick flows of hypersthene-andesite, with in some places intercalations of basic andesite and andesitic agglomerate.

We thus commence with basic material and ascend to outpourings and outbursts of acid lavas and tuffs, but these latter again were succeeded by more basic material, so that the volcanic sequence of this area not only shows, during part of the period, a marked increase in the acidity of its material, but also in its later phases there was evidently a return to the more basic conditions.

Over the greater portion of the area the dip of the volcanic series and its associated sedimentary zones varies from E.S.E. to S.S.E. It is usually at a low angle, but inclinations up to nearly 30 degrees have occasionally been observed. In the south-west corner of the map, in the area about Loch Scamadale, the dip is to the north-west. The volcanic series probably reaches its maximum thickness in the central portion of the region, in the area about Beinn Ghlas and Lochan Dubha. The thickness here is probably at least 2000 feet, but that of the entire series is probably considerably more. In the south-eastern portion of the area towards Loch Awe the covering of lavas is of no great thickness, and inliers of the older schists situated at various levels are of not uncommon occurrence. Outliers of the lavas and of the basal conglomerates are occasionally seen in the area between Loch Nant and the Pass of Brander. The situation and behaviour of these inliers and outliers serves to illustrate in a most instructive manner the remarkably uneven, or rather hilly, nature of the ground over which the lavas were poured out. We thus find inliers occasionally appearing amid the lavas on a hillside, or in the upper portions of the small glens, while the outliers are occasionally preserved as though clinging to the hillslopes of the metamorphic area. The older surface of schists was evidently very rugged and uneven, and possibly exhibited mountainous features such as we see in the same type of area at the present day. The conglomerates may thus have been piled up against steep slopes of the older rocks where the action of breakers would have been strong, and water-worn boulders would be carried down by streams. The breccias, so commonly seen at the base of the andesites in the absence of typical conglomerates, would doubtless, from their appearance and the local character of their materials, represent superficial accumulations, such as talus or scree material, so characteristic an accompaniment of the surface denudation of such an area. The presence, moreover, of the zones of conglomerates, sandstones, and shales at various horizons and in different localities shows that aqueous conditions

of a somewhat local character prevailed during probably the greater portion of the volcanic period.

With the general easterly and south-easterly inclination of the series in this area we get at the same time a gradual thinning out of the series in an easterly and south-easterly direction. The result of this is that we have a gradual overlapping of the higher flows, so that in the eastern portion of the area we find higher horizons resting upon the older rocks than is the case to the west. Thus, in the region near the Pass of Brander and near Loch Nant, we find the massive crystal-tuffs only separated from the older schists by comparatively thin intercalations of the basic flows, while in the eastern part of the Benderloch area these tuffs are occasionally found resting immediately upon the old platform.

H. K.

*Oban and Kilmore District.*—The succession of the Lower Old Red Sandstone rocks entering into the Oban and Kilmore region in descending order is as follows:—

*Acid Tuffs.*

|                                                                                                                                                                                                                                          | Feet.   |         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|---------|
| h. Porphyritic hypersthene-andesites with some basic andesite flows, ... ..                                                                                                                                                              | 300-400 | 500     |
| g. Basic andesites and basalt lavas with occasional basic tuffs and agglomerates, ...                                                                                                                                                    | 500-600 | 500     |
| f. Zone of red mudstones and sandstones with a thin concretionary limestone, locally developed, and underlain in places by tuffs and agglomerates, ... ..                                                                                | 30-40   | 50      |
| e. Basic andesite and basalt lavas and occasional basic tuffs or agglomerates, ... ..                                                                                                                                                    | 400     | 50      |
| d. Zone of sandstone and red mudstones and grey shales with plant remains ( <i>Pachythea</i> sp., &c.), ... ..                                                                                                                           | 50-100  | 100-150 |
| c. Basic andesite lava flow, ... ..                                                                                                                                                                                                      | ?       |         |
| b. Red and grey sandstones and shales with fossils, <i>Cephalaspis lornensis</i> , <i>Mesacanthus mitchelli</i> ,* <i>Thelodus</i> sp., <i>Pterygotus anglicus</i> , <i>Kampecaris forfarensis</i> , ostracods and plant remains, ... .. | 50-100  | 100-150 |
| a. Coarse conglomerates with occasional sandstones and at least one lava flow. Stones well rounded up to 3 or 4 feet in diameter, consisting of quartzite, andesite, granite, porphyrite, epidiorite, and various schists, ... ..        | 100-200 |         |

The rocks of Lower Old Red Sandstone age that form the Lorne plateau may be looked upon as being arranged in a shallow compound syncline whose axis trends north-east and south-west,

\*The remains of this fish, common in the Old Red Sandstone of Forfarshire, were found in the rocks of this zone at Gallanach, a little to the west of Oban, in Sheet 44.

truncated on the east by the fault traversing the Pass of Brander and continuing northwards across Loch Etive through Glen Salach. This synclinal structure is partially concealed by local minor folds and by a more or less constant overlap of higher strata on to the uneven floor of metamorphic rocks in a direction from north-west to south-east. Moreover, the basin is cut up into sections by two systems of faults nearly at right angles to each other, those of the earlier system having a general north-east and south-west direction, and it is further traversed by a double system of intrusive dykes. The earlier of these, with a north-east and south-west trend, more or less parallel with the earlier faults, are of the same general age as the volcanic rocks of the region, though necessarily of a slightly later date than those which they actually penetrate, while the latter dykes, running in a nearly north-west and south-east direction nearly parallel with the later faults, are of Tertiary age.

In consequence of the above arrangement the lowest members of the series, which, as already stated, are mostly sedimentary, shown in Fig. 1, are best developed in the Oban portion of the region along the north-west edge of the syncline. Accordingly the lower conglomerates (a, Fig. 1) and sandstones (b), which here attain their maximum thickness, and dip to the south-east at about  $20^{\circ}$ , form the islands at the mouth of Loch Etive, as well as a considerable stripe of country extending along the coast from Dunstaffnage westwards to the edge of the map. To the south-east they dip beneath a basic lava-flow (c), but owing to the system of step faults already mentioned, the coarse basement conglomerate with its outlying sandstones and shales, together with a basic lava-flow very local in its development, are repeatedly brought to the surface for some distance to the southwards. These sedimentary rocks, therefore, underlie the greater part of the area upon which the upper part of Oban is built, and also form a considerable portion of the cliff that overhangs the town. They also extend up Glen Crutten, giving rise to most of the escarpments that bound the floor of the glen composed of raised beaches and lake alluvia.

It is from the sandstones and shales at the top of this series that the fossils were obtained which determined the exact geological age of the rocks of the Lorne volcanic plateau. The chief fossiliferous locality is within Oban itself, in a cliff near Selma Cottage, situated at about 200 yards N.N.E. from the North Quay, and at a height of about 300 feet above sea level. The flaggy sandstones which constitute the cliff have been quarried partly for the purposes of widening the roadway and partly for building material, and have yielded numerous specimens of *Cephalaspis lornensis*, Traquair,\* a form very nearly allied to *C. lyelli*,† which is characteristic of the Lower Old Red Sandstone of Forfarshire and the Welsh Border.

The other locality within the present map is in the railway

\* *Nature*, 17th June, 1897, vol. lvi., p. 157.

† *Mem. Geol. Sur.*—Summary of Progress, 1897, pp. 82-83.

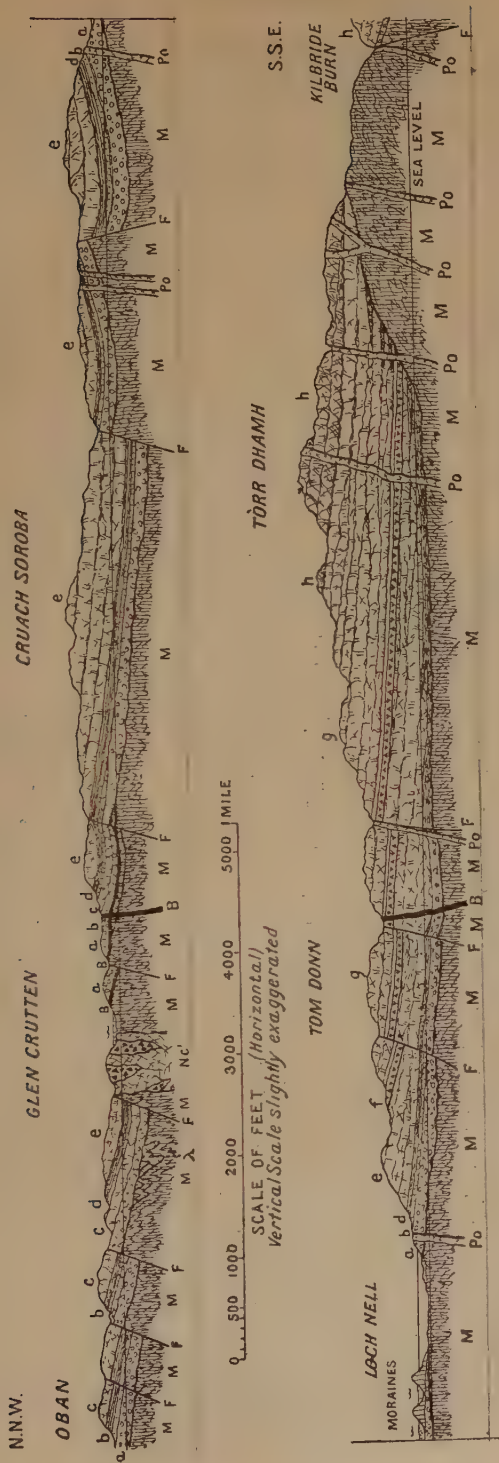


FIG. 1.—Horizontal section from Oban across the Volcanic Plateau of Lorne to Kilbride Burn.

Metamorphic—M. Black schists, phyllites, and limestones. Lower Old Red Sandstone—*a*. Basement conglomerate; *b*. Sandstones and shales with *Cephalaspis*; *c*. Basic lavas; *d*. Sandstones and shales with plant remains; *e*. Basic andesite and basalt lavas; *f*. Agglomerates and tuffs, red mudstones and sandstones; *g*. Basic andesite and basalt lavas; *h*. Hypersthene andesite lavas. Intrusive Igneous Rocks—*Po*. Porphyrites of Lower Old Red Sandstone age. Tertiary—*B*. Basalts. Recent—*~* Raised beaches. *F*. Faults. *N* = North.



cutting a little to the north-east of Dalintart Farm in Glen Crutten, where the shales, in addition to *C. lornensis*, have yielded *Pterygotus anglicus* and *Kampecaris forfarenensis*, arthropods also found in the equivalent rocks of Forfarshire. The underlying conglomerate (a), which has here diminished to less than 50 feet in thickness, is more sandy than at Oban and has smaller pebbles, composed mostly of quartzite.

To the east and south of Oban and Glen Crutten the fossiliferous strata (b) dip to the south-east and pass under strata consisting chiefly of lava-flows; but, owing partly to reversal of dip and partly to faulting, they reappear near Loch Nell, and are exposed on both sides of the loch, near the foot of which they roll over an anticline. The lowest beds visible consist of conglomerates (a), but there is every reason to believe that the bed of the loch is carved out of metamorphic rocks which must form the core of the fold. To the south of the loch where the south-east dip is resumed the sediments once more disappear beneath the lavas, and in consequence of the overlap already mentioned must soon run out against the old floor as shown in the horizontal section (Fig. 1), for, where the metamorphic rocks once more emerge in the Kilbride inlier about two miles to the south-east, the hypersthene-andesite-lavas of group (h), about 1000 feet higher up in the succession, rest directly on the black schists and limestones. Eastwards from Oban the overlap is even more rapid, for in the Achavaich inlier near Connel, already mentioned, the metamorphic rocks are immediately overlain by basic andesites without the intervention of any sedimentary rock belonging either to groups (a) or (b).

(c). The basic andesite lava-flow (c), stepped by faults, follows the outcrop of the fossiliferous band (b), and is usually found capping the cliff overhanging Oban and Glen Crutten.

(d). The lava-flow last mentioned is followed in turn by a belt of sediment, consisting chiefly of red and grey mudstones, sandstones, and shales. Broken up into segments by the double system of faults, its outcrop has been traced at intervals from Pennyfuir,  $1\frac{1}{2}$  miles north-east of Oban, round the cliffs bounding Oban and Glen Crutten to Soroba House, where the band passes into Sheet 44. It is also exposed in the railway cutting on the Connel side of the watershed and at Ardchonnell, about a mile from Connel Ferry. This band appears to die out rapidly to the south, as it has not been recognised on the Loch Nell anticline.

(e). The basic andesites and basalt lavas of zone (c) form the bulk of the rocks entering into the ground lying to the west of a line drawn from a point a little to the east of Connel Ferry, along the course of Gusragan Burn, through Loch Nell to Loch Feochan and the outcrop of the last-mentioned sedimentary band (d). East of Loch Nell they form a stripe of over  $\frac{1}{4}$ -mile in breadth, and floor the Feochan Bheag valley to a little above Dalnacabeg, more than a mile east of Kilmore. The rocks are chiefly fine-grained, dark bluish or purplish when tolerably fresh, but reddish when decomposed. The individual flows are usually slaggy at

top and bottom, and sometimes show traces of flow structure and flow brecciation. One of the flows at or near the base of the group, having a considerable development and making up a good part of the ground to the north of Glen Crutten, differs somewhat from the rest in being greyish or fawn-coloured. It shows marked fluxion banding, and has its steam vesicles much drawn out as if it had flowed in a highly viscid state, and altogether appears to be a less basic rock than the others. This flow, however, derives its chief importance from being identical in character with a rock which fills the greater part of a vent or neck (to be described in the sequel), which occurs close to Glen Crutten farmhouse, about one mile east from Oban. The lavas of the group usually have the cracks and irregularities of their surfaces filled in with more or less clastic material, marking short pauses in the volcanic activity of the period, and occasionally there is an intercalation of tuff or agglomerate made up of the same material as the lava-flows. Such rocks occur close to Connel Ferry at the roadside. Exposures of tuff are also found at Benbeg, about halfway between Connel Ferry and Oban, where, owing to the synclinal arrangement of the strata, they cap low hillocks, thus forming the highest rocks of the neighbourhood. These may even be outliers of the overlying succeeding belt (f).

(f). The outcrop of this zone, much interrupted by faults, has been traced from Torr-an-tuirc, near the head of Loch Nell, to Barnacarry, and thence along the slopes overlooking Kilmore up the Feochan Bheag valley to beyond Dalnacabeg, where it crosses the river at a waterfall. Near Torr-an-tuirc it consists chiefly of a basic tuff, which makes it highly probable that the exposures already mentioned as occurring at Benbeg are outliers of this band. In the slopes above Kilbride the tuff is overlain by red mudstones with an occasional thin impure concretionary limestone. Where the zone crosses the Feochan Bheag it is composed chiefly of red shales, overlain by red sandstones, and succeeded by a bed of greenish shale, which is surmounted by the basement lava of the succeeding groups. The waterfall above referred to is due to the weathering out of the shaly beds beneath the harder strata, especially the lavas (g), and to the dip being upstream. In fact, the erosion of this band everywhere gives rise to waterfalls in streams as well as to cliffs and landslips on the hill slopes. On the south side of the Feochan Bheag the solid rock is much concealed by moraines and by landslipped masses further up the slopes, so that the zone has not been accurately traced; but its position is fairly well indicated by the persistent crag that overhangs the valley, from which the landslipped masses have been derived. Owing to a change of dip to the north-west along a line drawn south from Craigentaggart, the outcrop of the band must gradually descend the hill slope and pass below sea level near the head of Loch Feochan. The thin belt of ash and red shale dipping to the north-west, which crosses the valley of the River Euchar below Loch Scamadale, is probably the continuation of this zone beneath the overlying pile of lavas. On the south side

of the valley the ash is accompanied by red shales, and also gives rise to extensive landslips.

(g). The rocks of this group of lavas are almost identical in character with those of group (e). With the exception of an occasional thin bed of tuff, we find a constant succession of lavas. Still there is a slight difference in texture and in the thickness of the individual flows, which gives rise to more conspicuous escarpments in some cases.

The members of this group form the greater part of the mass of high ground lying between Loch Nell and the Feochan Bheag from the outcrop of the sedimentary band (f) up to a line drawn southwards from Clenamachie round the west shoulder of Torr Dhamh, and eastwards to the fault that truncates the Kilbride inlier. In this block the dip is everywhere persistently to the south-east. South of the Feochan Bheag these lavas constitute the greater part of the high ground between that valley and Scamadale west of the line of fault which truncates the Kilbride inlier, and which is continued along the course of the Eas Ruadh to Scamadale Farm. In this block of ground west of a line drawn roughly from Craigentaggart in the Feochan Bheag valley to Scamadale farmhouse there is a roll over to the north-west, and there is probably a greater thickness of material and a greater number of flows than in the ground to the north of the Feochan Bheag.

(h). Hypersthene-andesite lavas chiefly characterise the rocks of this zone and are conspicuously porphyritic. The individual flows are also appreciably thicker than those of the former group, and in consequence give rise to more prominent escarpments. In the present area they mostly lie east of a line drawn from Kilmaronag on Loch Etive through the upper Black Lochs southwards to Clenamachie and the head of Loch Scamadale. A few outliers of these porphyritic lavas, however, cap the hills to the west of the line north of Scamadale. To the east of the above line hypersthene-andesite lavas, alternating with basic andesite flows like those of the former group, form the ground eastwards to the outcrop of the acid tuff indicated by Mr. Kynaston as entering this part of the plateau south of Loch Etive at Achnaclloch, and traceable at intervals to Glen Lonan. South of this point their upper limit is bounded partly by the outcrop of that band and partly by the acid lava flow already described by Mr. Kynaston.

*Volcanic Vent of Lower Old Red Sandstone Age.*—One of the vents which probably supplied material to build up part of the Lorne volcanic plateau occurs in Glen Crutten, close to Glen Crutten farmhouse, about  $\frac{3}{4}$ -mile east of Oban, as shown in Sheet 45 and in Fig. 1. The vent or neck, which is hour-glass shaped and about  $\frac{1}{4}$ -mile long, is filled partly with a coarse volcanic breccia made up of fragments of andesite and metamorphic rocks, and partly with a greyish-coloured andesite. These materials rise through the black schists on the west side and through the overlying Old Red basement conglomerate and sandstones on the east, the junctions where visible being more or less vertical. The



neck appears to be truncated on the north by the Glen Crutten fault, one of the series of north-east and south-west faults with downthrow to the north that step the structures so conspicuously in the Oban region. The grey andesitic rock found in the vent is in part massive, but in places shows a marked platy structure with drawn-out steam vesicles, the fluxion planes being more or less vertical. Where the rock exhibits these characters it exactly resembles the lava-flow already mentioned as occurring at or near the base of group (e), which evidently emanated from this centre.

B. N. P.

ii. *Petrology of the Volcanic Series.*—During the course of the mapping of the Lorne volcanic area, numerous specimens of the different types and varieties of lavas were collected, and a number of these were selected for microscopic examination. The results of this examination proved of great value in determining the distribution of the different types in the field and their petrological relationship. It will be of interest, therefore, to give a short account of the petrological characters of the principal types of lavas represented in this area.

1. *The Basic Andesites.*—The general field characters of these rocks have already been described. In hand specimens the rocks are either close-grained and compact, or highly vesicular. They are almost black when fresh, and frequently bear a close resemblance to basalts. In fact, it would be more correct to class some of the flows with the basalts than with the andesites. Porphyritic varieties often occur, but perhaps the commoner type is a dark dense rock without conspicuous porphyritic feldspars, though frequently showing numerous small reddish-brown scales, resembling the mineral described under the name of iddingsite. These rocks are often highly decomposed, thus rendering microscopic examination somewhat unsatisfactory.

Basic andesites are well developed in the neighbourhood of Taynuilt, and fairly fresh examples from that area have been studied under the microscope. Specimens from Cruach Ard-dhuine, S.S.W. of Taynuilt, are black fine-grained rocks closely resembling basalts, and often very vesicular. Under the microscope they show [9628-9631] pseudomorphs of calcite and limonite, and sometimes of serpentine, after olivine, and these are usually the only phenocrysts. The ground-mass is often somewhat coarse-grained, consisting of lath-shaped plagioclases, with a fluidal arrangement, brownish augite, and ilmenite in skeleton crystals and flattened scales. This ground-mass is intersertal, the pyroxene being in great part moulded on the feldspar (subophitic), and is usually quite holocrystalline. Occasionally the augites are fairly idiomorphic [9628], and in some cases a dark interstitial matter is present which probably represents an original glassy base [9630]. Apatite is also present, with secondary calcite, limonite, and chlorite. As a general rule in these rocks the feldspar greatly predominates over the ferromagnesian constituents, so that they perhaps belong rather to the basic andesites than to the olivine-basalts, while representing intermediate types between the andesites and the basalts.



The basic lavas of this type pass by gradations into the typical hypersthene-andesite. The phenocrysts of olivine become fewer and hypersthene makes its appearance, and phenocrysts of plagioclase become more common. A good example of this kind of lava occurs at Creag Mhic Rìgh, a conspicuous crag about  $1\frac{1}{2}$  miles S.S.W. of Taynuilt. The microscope shows [9627] chlorite after porphyritic augite, bastite after hypersthene, black heaps of granular magnetite apparently from the resorption of biotite, and opaque masses of iron oxides after olivine, in an abundant, rather coarse-grained, fluidal, non-vesicular ground-mass, which consists entirely of lath-shaped plagioclase feldspars, mixed with iron oxides and secondary calcite. Much chlorite interspersed among the feldspars seems to indicate the former presence of a second generation of pyroxene. No porphyritic feldspars are present in the slide. In some specimens, however, taken from a similar type of rock one mile north of Barachander, north of Kilchrenan, porphyritic plagioclases are well seen [7409, 9022-9024]. The microscope also shows porphyritic augites, some enstatite, and a few pseudomorphs after olivine, in a ground-mass consisting of small plagioclase laths, pyroxene grains, and magnetite.

2. *The Hypersthene-Andesites.*—These cover a considerable area in the more central portion of the volcanic plateau. They are dark grey or purple rocks with conspicuous phenocrysts of plagioclase and greenish pseudomorphs after hypersthene. Vesicular varieties are also common. Typical hypersthene-andesites occur on the east side of Glen Nant [7408, 7589], and cover a large area to the west of Taynuilt. A specimen from the roadside quarry,  $1\frac{1}{2}$  miles north-west of Taynuilt, shows under the microscope [9632] phenocrysts of plagioclase honeycombed with glass enclosures and slightly corroded. There is much bastite after idiomorphic hypersthene, and pseudomorphs of calcite possibly after augite. The ground-mass is of the very fine-grained pilotaxitic type, consisting principally of minute feldspars. This matrix contains granules of quartz which are probably secondary, and little irregular vesicles full of quartz, chlorite, and a semi-opaque material. In some examples the ground-mass seems to have been fairly glassy [9634]. The rock from the quarry at Australia, north-west of Taynuilt, shows good phenocrysts of plagioclase, hypersthene, and augite [9635]. The hypersthene is usually altered to bastite, but the augite is often fairly fresh. The feldspars give extinctions indicating labradorite to andesine. A specimen of the same rock,  $2\frac{1}{2}$  miles west of Taynuilt [9636], shows a ground-mass which seems to have been largely a glass with forked feldspar microlites, but which is now dusty and devitrified, and filled with calcite and secondary quartz. Apatite is usually present as an accessory, and is occasionally pleochroic [9637].

Conspicuously porphyritic andesites again cover a large area to the south of Kilbride, near the head of Glenfeochan. Under the microscope [10129] these rocks appear as rather decomposed

hypersthene-andesites, in which the hypersthene is replaced by bastite, and with the pilotaxitic type of ground-mass.

About a mile to the east of Kilbride and in the crags on the north and north-east sides of Beinn Ghlas, we find porphyritic andesites which appear to be transitional between the typical hypersthene-andesites and the hornblende- and mica-andesites [10130-10132 and 10144-10146]. These rocks appear to be of a slightly more acid type, and contain biotite and occasionally resorption pseudomorphs after hornblende as well as hypersthene, in a pilotaxitic or hyalopilitic ground-mass.

3. *Hornblende- and Mica-Andesites*.—These rocks only occupy a comparatively small proportion of the volcanic area, compared with the more basic types. They are well developed in Glen Nant, on both sides of the glen in the neighbourhood of Tailor's Leap, and mica-andesites occur in considerable masses, as already pointed out, about the high ground to the south of Glen Lonan.

Hornblende-andesites occur at Tailor's Leap, Glen Nant, and in the same glen about three miles south-east of Taynuilt. They are usually considerably altered, and the hornblendes are pseudomorphosed and show black resorption borders [7590, 7591]. Sometimes pseudomorphs of another ferromagnesian mineral are also present, probably augite [7591]. In the burn to the west of Tailor's Leap we find mica- and mica-hornblende-andesites.

A section of the mica-hornblende-andesite shows corroded brown biotite and greenish-brown hornblende, with some pale green augite; several rounded quartz grains (xenocrysts) with corrosion borders of pale green pyroxene, partly replaced by calcite. The ground-mass consists of rather well-formed small lath-shaped feldspars, irregularly scattered, and mixed with magnetite and decomposition products. There are no porphyritic feldspars seen in this section, but they are usually fairly common [9639]. The biotites and hornblendes frequently have intense black corrosion borders [9639]. In the mica-andesite [9638] the biotite is usually represented by pseudomorphs of granular magnetite, though occasionally a little fresh biotite remains. Other pseudomorphs are also present possibly after pyroxene. The ground-mass consists of fairly large lath-shaped fluidal plagioclase, rather trachytic in aspect and not glassy, containing secondary quartz, calcite, &c. There is much magnetite in small grains and irregular masses. Vesicles of irregular shape are also present.

4. *Felsitic Lavas*.—These rocks are perhaps most typically developed in Glen Nant, also in Airds Park, to the north-west of Taynuilt, and again to the west and south-west of the same place. They are characterised by their pale colour, compact and flinty texture, and the well-developed fluxion banding. Spherulitic and nodular varieties are also occasionally met with. They are frequently associated with the hornblende- and mica-andesites, and are certainly more acid, and represent the most acid phase among the lavas of this area. The banded felsites of Glen Nant are seen under the microscope [7593-7596] to contain phenocrysts of

felspar, which, in part at least, is plagioclase, and frequently biotite as well. They may perhaps represent rhyolitic forms of a somewhat acid biotite-andesite. They do not contain phenocrysts of quartz, and can therefore scarcely be referred to dacites or true rhyolites, while the presence of plagioclase would seem rather to connect them with the andesites. In one of the sections [7596] an idiomorphic phenocryst of orthoclase is seen, containing a core of plagioclase. This would tend to indicate some affinity with the trachytes.

The felsitic rock of Airds Park [9642, 9643] shows phenocrysts of plagioclase and biotite in a felsitic ground-mass, sometimes of the spotted felsitic type, throughout which are scattered small felspar microliths and infiltrations of quartz. A specimen from Monadh Glas, about two miles south-west of Taynuilt [9644], shows a few felspar phenocrysts, some of which are untwinned or simply twinned, and probably include sanidine. The felsitic matrix shows good flow structure, and in places contains imperfect spherulites.

From these descriptions it would appear that these rocks belong to acid types intermediate between biotite-andesite and rhyolite.

5. *The Tuffs*.—The petrological characters of these rocks have been described in the paper, already referred to above, on some tuffs associated with the andesitic lavas of Lorne. It will therefore suffice here to give a short account of the more interesting features. The more acid type of tuff is exposed in the western portion of Benderloch, at Airds Point, and on Cruach Ardhruine, S.S.W. of Taynuilt. It is usually compact and flinty in texture, and varies in colour from reddish-purple to a pale yellowish or sometimes grey tint. It is often crowded with small fragments of felsite and with some andesite, and shows biotite flakes and crystals of an acid felspar. There is very little difference between these tuffs and those which cover larger areas in the more eastern portion of Benderloch, in the ground south of Achnacloich, and in the area about the Sior Lochs. These latter tuffs would appear to contain more numerous felspar crystals, and to have their lapilli more largely made up of andesitic fragments than of felsitic. Under the microscope the structural peculiarities of the two varieties are fairly similar. For palæozoic tuffs these rocks have retained their original characters remarkably well.

Sections of the more typical examples [7247, 7598, 7404, 7706, 9646-9651] show broken and more or less corroded crystals of sanidine, some plagioclase, biotite flakes, grains of magnetite, and lapilli. The sanidine is often clear and very fresh, and shows the normal twinning on the Carlsbad plan. The amount of plagioclase (oligoclase or andesine) varies in different sections, and the mineral is usually more or less turbid from alteration. The biotite is of the variety characteristic of the hornblende-andesites and trachytes. It is sometimes bent and often bleached from alteration, and occasionally partially or entirely replaced by granular iron-ore. Hornblende is also some-



times present, but is usually represented by chloritic alteration products.

The general matrix seems to be almost purely volcanic. In many cases it is a good deal altered, but the clastic character is nearly always still evident. The characteristic feature of this matrix is the beautiful ash-structure (aschen- and bogenstruktur of German petrographers) which it frequently presents. Some sections show this in a very perfect manner [7706, 7716, 7592]. The appearance is more or less similar in each section. We see numerous small, more or less clear, irregular fragments and particles, sometimes concavo-convex in outline, and sometimes bi-concave, packed closely together. Sometimes the fragments contain infilled vesicles, and in some cases [7706] many of the smaller lapilli consist of highly vesicular fragments with ragged outlines. Frequently the fragments and finer particles lie with their longer axes approximately parallel, indicating a lamination of the material, or again they may alternate with a still finer and more dust-like type of matrix. There seems to be no doubt that these fragments were originally glassy, and were derived from the shattering of a highly vesicular lava resembling pumice. This structure has been well described and illustrated by Mügge in a study of some acid tuffs associated with sodarhyolites in the Devonian of the Lenne district in Westphalia.\* These rocks show very clearly the characteristic forms of the constituent ash-particles, bounded by concave curves, which are so suggestive of broken-up pumice.

The lapilli of these tuffs appear to be mainly andesitic, though in the more acid varieties fragments of felsite are often more common. The andesitic lapilli contain plagioclase phenocrysts in a ground-mass rendered dark and sometimes almost opaque by minute granules of magnetite. The ferromagnesian constituents are usually too decomposed for identification. It is probable, however, that most of the andesitic fragments represent the pyroxene- and basic-andesites so common in the surrounding area. Occasionally a fragment is seen [7247] of more acid, or rather trachytic, character, containing phenocrysts of sanidine, and probably representing a portion of the parent rock from which the numerous sanidine crystals in the tuffs were derived. Lapilli of hornblende-andesite are fairly common [7246, 7722], and these closely resemble the hornblende-andesites which are found below the tuffs in Glen Nant. A section of one of these fragments [7722] shows phenocrysts of idiomorphic hornblende, biotite, plagioclase, and some corroded quartz grains. The hornblende has the characteristic outlines of the brown variety characteristic of the hornblende-andesites, but it is now almost completely replaced by granules of iron-ore, as is so frequently the case in rocks of this type. The biotite shows a deep resorption border, within which the original substance of

\* Mügge—"Untersuchungen über die Lennenporphyre in Westfalen und den angrenzenden Gebieten," Neu. Jahrb. Beil. Bd. viii. (1893), p. 648, pl. xxiv., figs. 20 and 21.



the mineral is bleached and almost colourless. The quartz grains would seem to be original; they are more or less corroded, and show characteristic inlets and inclusions of the ground-mass. Their presence allies the rock to the dacites. In some of the lapilli of this type [7246] the biotite is in excess of the hornblende. The ground-mass is much obscured by specks of iron-ore and alteration products, but is seen to consist largely of small felspar microlites.

Non-volcanic fragments derived from the older platform of crystalline schists are occasionally met with, and are perhaps more frequently seen in the more felsitic types of tuff. One of the sections [7717] shows a lapillus consisting of a schistose rock containing biotite, sericitic mica, quartz, and felspar, with a few small garnets. Fragments of quartzite are also sometimes seen.

Tuffs of this type, with such well-preserved "ash-structure," have not yet been described from any other area of Lower Old Red Sandstone volcanic rocks in this country. The "ash-structure" most nearly resembles that of the acid tuffs described by Mügge, and already referred to. Recently a somewhat similar structure has been described in a brecciated soda-felsite from Wicklow Head in Ireland,\* but in this case the structure is apparently due to the breaking up of a glass by brecciation in situ. In the case of our Lorne rocks there can be little doubt that the "ash-structure" is the product of showers of minute glassy particles ejected from a volcanic orifice by discharges of a highly explosive character. The characteristic form of the glassy particles is doubtless due to the immense quantity of gas bubbles and steam cavities present in the molten mass at the time of eruption.

The petrological characters of the Lorne lavas correspond remarkably closely with those of the rocks of other volcanic areas of the same age. Thus, the basic lavas and pyroxene-andesites of the Cheviots, the Pentlands, the Ochils, the Ayrshire coast, and other areas bear a close resemblance to those of Lorne. Biotite-andesites are known from the Cheviots, but only from the lower part of the volcanic series. They occur at Camphill in the South-eastern Pentlands, and near Dollar in the Ochils. Acid flows are not known from the Cheviots, but they occur in the Pentlands and Ochils. Some of the banded felsitic rocks found in the Pentlands strongly recall those of Glen Nant, and portions of the Craig Rossie rock, in Perthshire, closely resemble some of the acid types of Lorne. Felsitic tuffs also occur in other Lower Old Red Sandstone areas, but the characteristic "ash-structure" has so far only been described in the Argyllshire tuffs.

H. K.

*Lismore.*—At Sliabh nam Ban-fionn, half a mile west by south of Fennacrochan, a breccia of a peculiar kind lies unconformably on the limestone and black schist. It consists of fragments of schistose limestone with a few of black schist embedded in a calcareous matrix. Most of the limestone fragments vary in size

\* *Summ. Prog. Geol. Survey for 1899*, p. 179.

from one to six inches, but are mixed with larger blocks which sometimes reach a length of six feet. The small pebbles are sometimes almost rounded, but the larger blocks are angular and sub-angular. The breccia, whilst being obviously younger than the great denudation which took place after the foliation of the schists, has undergone considerable contact alteration by the neighbouring mass of diorite, which is presumably of Old Red Sandstone age. In its internal structure and in its relation to the schists it bears a striking similarity to certain scree-like breccias occurring beneath and around the Lower Old Red volcanic rocks of Glencoe. For these reasons the breccia has been classed as doubtful Lower Old Red Sandstone age (*c*<sup>1</sup>?), but it must be understood that the breccia has little in common with the well-rolled conglomerates lying at the base of the Lorne volcanic rocks, or with another type of Old Red Sandstone, an outlier of which occurs near Kilmalieu in Ardgour (Sheet 53), less than eight miles to the north-north-east.

H. B. M.

## CHAPTER VIII

### NEWER IGNEOUS ROCKS.

Under this title will be described here those rocks which have been intruded into the metamorphic series at a later date than the movements which caused their foliation. In the present sheet they comprise the granite masses of Ben Cruachan, the Blackmount, and Glen Fyne, and their more basic modifications, outlying masses, and associated dykes.

i. *Ben Cruachan Granite and Outlying Masses.*—Under the term “Ben Cruachan Granite” we may conveniently describe the large mass of granite which extends from the north-east slopes of the Pass of Brander to the northern margin of the sheet, and as far eastwards as the watershed between Loch Etive and Glen Stræ. On the west side of Loch Etive the granite occupies another broad belt reaching on the west the watershed between Loch Etive and Loch Creran. The whole area covered by the Ben Cruachan granite on the present map alone is probably at least 100 square miles, and constitutes the wildest and most mountainous portion of this part of Argyllshire (Plate V.).

What may be termed the Ben Cruachan granite proper forms the great mass of Ben Cruachan itself and the line of hills on the north side of Glen Noe, extending eastwards to Beinn a' Chochuill and Beinn Eunaich, and thence north-eastwards along the south side of Glen Kinglass to Meall Garbh. To the north of this tract the rest of the granitic area consists of a slightly later and more acid type of granite, sharply marked off from that of Ben Cruachan. In the north-east corner of the map the Ben Cruachan type of granite comes on again at the west end of Loch Dochard, and extends northwards to Stob Ghabhar. The same type again forms the outlying masses around Clais gobhair. On the west side of Loch Etive similar relations are seen between the two types, that of Ben Cruachan extending northwards from Bonawe Ferry to Beinn Sguliaird, and forming, as it were, an outer border or fringe to the more acid type, while the latter occupies the more central portion of the granite area. The boundary line between the two types is usually quite distinct, the latter or Blackmount type being the coarser and more acid and conspicuously porphyritic. Occasionally, however, the two granites appear to pass gradually the one into the other.

The Blackmount type of granite forms a roughly oval mass, of fairly regular outline, extending northward into Sheet 53. On its outer margin it is everywhere in contact with the Ben Cruachan granite, except for about two miles on the east side of

Glen Kinglass, where the Cruachan granite is not seen, and the more acid type is brought against the schists.

The outer margin of the Ben Cruachan granite is, on the whole, sharply defined and easy to follow in the field. This is more especially the case along the west side of Glen Strae and on the northern slopes of the Pass of Brander; but in the area between Loch Etive and Loch Creran the boundary line becomes exceedingly irregular, and constitutes a marginal area of great complexity. To the east of Loch Creran the contact zone between the granite and the schists consists of a network of sills, veins, bands, and tongue-like protrusions of granite, covering a belt of mountainous ground sometimes over a mile in breadth. The vein-like offshoots do not, as a rule, anastomose with one another, but tend to run in a roughly parallel direction, coinciding with the planes of foliation in the schists, although veins and irregular intrusions, having apparently no relation to any such planes, are not uncommon. The complication is such that a line can only with difficulty be drawn between the schists crowded with granite veins and sill-like bands and the granite crowded with strips and inclusions of altered schist of every size up to a mile or more in length. The contact area thus constitutes a zone of vein-like injections of great complexity. Furthermore, towards the inner portion of this injection zone, *i.e.*, as we approach the main mass of the granite, the schists are seen to be so impregnated with granitic material that it is impossible in a hand specimen to distinguish clearly the igneous portion from the material of sedimentary origin. The originally finely-banded character of most of these schists doubtless largely assisted the impregnation, which appears to be clearly parallel to the type of injection termed "*lit par lit*." The same structure has also been observed close to the main mass of the granite in the banded calcareous schists of the Pass of Brander, where both "*injection lit par lit*" and "superposition" (Michel Lévy) may be seen sometimes in the same specimen.

Again, in many places the schists have been broken up under the process of injection, and a breccia has been formed, occasionally at some distance from the main mass of the granite, consisting of a confused intermingling of altered schistose fragments in a granitic matrix. The fragments in these breccias are angular and usually sharply marked off from the matrix. Occasionally, however, the outline is not well defined, and appears indistinct with a lens, showing, as it were, a gradual transition from the included fragment to the matrix. Such fragments are usually crowded with flakes of secondary biotite in more or less parallel layers, and are somewhat suggestive of the origin of certain ill-defined patches rich in biotite occasionally seen within the granite. Sometimes the breccia is very coarse, as is well seen on the west side of Meall Garbh, the fragments measuring several feet in diameter. This structure was evidently an accompaniment of the intrusion, and is seen to involve homogeneous rocks, such as quartzite, as well as the various types of hornfelsed schist.



Thus in the marginal area of the granite every kind of injection may be observed from sill-like protrusions of the main mass, many yards in breadth, to injections of microscopic dimensions. And similarly the granite contains included portions of the schists, varying from masses more than a mile in length to minute fragments. Even the smallest granite veins are comparatively coarse in texture throughout, and are usually of the same texture as the main mass to which they belong.

The normal type of rock which constitutes the Ben Cruachan mass is a hornblende-biotite-granite of medium, though sometimes of fairly coarse grain, and grey in colour. This is the most persistent and widespread type. The microscope shows both plagioclase and orthoclase, of which, however, the former (probably oligoclase) largely predominates. A greenish hornblende is conspicuous, and is frequently associated in groups with the dark brown biotite. Quartz is but sparingly distributed in small grains and aggregates, and is interstitial. Apatite, magnetite, and pyrites, with a few small grains of sphene, occur as accessories.

Two other types may also be distinguished in the Cruachan mass, the one a more acid and the other a more basic type. The first constitutes almost the whole of the topmost portions of Ben Cruachan and of many of the neighbouring hills. It is occasionally seen on the shore of Loch Etive, and forms a considerable part of the high ground from Beinn Duirinnis, north of Bonawe Ferry, to Beinn Sguliaird, on the northern boundary of the map. It consists of a tolerably coarse pink granite, in which the dominant minerals are pink orthoclase and quartz. This decidedly more acid type may sometimes be seen to pass imperceptibly into the normal grey granite, or to occur in fairly well-defined bands and patches.

The more basic type is of less common occurrence. It is a dark grey medium-grained rock, consisting mainly of green hornblende, biotite, and plagioclase, while the orthoclase and quartz, if not almost entirely suppressed, occur merely as accessory constituents, so that this type would more correctly be termed diorite than granite. It appears in small patches near Port-na-mine, about two miles north-east of Bonawe, and in larger masses along the ridge of hills on the north side of Glen Noe. This rock is never sharply marked off from the normal type of hornblende-granite, but passes imperceptibly into it, and doubtless represents merely a slightly more basic modification of the magma.

The marginal portion of the granite mass, especially along the Pass of Brander and on the south slopes of Beinn-a-Bhuiridh, and to the north-west of the head of Loch Awe, is usually slightly more basic and finer-grained than the main mass. Where, however, the boundary line is irregular and consists of a complex of veins, as in the ground between Loch Etive and Loch Creran, there is no marked modification either in composition or texture. The finer-grained variety is well seen in the Bonawe

quarries, where it has for many years been largely worked for granite sets. Under the microscope plagioclase is seen to be the dominant felspar in this rock, and it is usually zoned and idiomorphic, while biotite, interstitial quartz, and alkali-felspar (microcline in part) are also present. The coarser and typical granite is well seen further to the north-east in the Craig Point quarries, and it forms the greater portion of Beinn Duirinnis, though here and there, especially about the top of the hill, the more acid pink granite occasionally makes its appearance.

The dioritic phase is well exposed on the south-western and southern slopes of Beinn-a-Bhuiridh, and on Monadh Driseag, to the west of the head of Loch Awe, and coarse grey dioritic varieties are largely worked in the Loch Awe quarries further to the north-east. A specimen from the south-west side of Beinn-a-Bhuiridh is seen, under the microscope, to be largely composed of a zoned plagioclase, full of minute inclusions arranged in definite planes, together with biotite, hornblende, interstitial quartz, and a little alkali-felspar. Spheue, iron-ores, and apatite occur as accessories. Dr. Teall, who has examined these rocks, calls it a quartz-biotite-diorite, and remarks that the plagioclase is exactly similar to that of the rocks belonging to the hyperite-facies of the Southern Upland granites. Other portions again of the Beinn-a-Bhuiridh diorite are still more basic, and contain brown hornblende and a pale greenish pyroxene (augite-biotite-diorite)—another point of resemblance to the Southern Upland series. The diorite on the south side of Beinn-a-Bhuiridh and on Monadh Driseag is somewhat similar, consisting of zoned plagioclase (oligoclase-andesite), biotite, brown hornblende, interstitial quartz, and micro-pegmatite, the two latter constituents appearing only in very small quantity. Further to the north-east, in the Loch Awe quarries, the rock is coarser, but of more or less similar composition.

As we follow the Ben Cruachan granite from this area in a north-easterly direction, it is found on the east side of Glen Kinglass, to die out against the more acid mass of the Blackmount and Glen Etive. We pick up the Cruachan type again, however, about a mile south-west of Loch Dochard. Here it rapidly widens from a breadth of only a few yards to nearly half a mile, and assumes a fairly coarse texture. It is a pinkish hornblende-granitite, becoming fine-grained and dioritic in appearance at its junction with the quartzose schists to the east. To the north of Loch Dochard the Cruachan granite rapidly spreads out over a wider area, the boundary line passing through the ridge of Stob Ghabhar, and thence into Sheet 53 to the north. To the south and south-east of Stob Ghabhar, a separate mass of the same general type is seen in the neighbourhood of Clais-gobhair. This mass is exposed for a mile and a half in the Clais-gobhair Burn, and is continued north-eastwards as a narrow strip as far as the margin of the map. The rock is a medium-grained greyish, and sometimes pinkish, hornblende-granite. Under the microscope [8620] it is seen to consist of plagioclase-felspar,

green hornblende, biotite, and a small proportion of alkali-felspar and interstitial quartz, sphene, apatite, and iron-ores occurring as accessories. Further to the east occurs another mass of similar general type, varying from hornblende-granite to diorite. Only a portion of this mass is seen within the present sheet.

We will now pass on to the more acid mass of granite, which forms, as already pointed out above, a kind of central core to the granite of Ben Cruachan type. This rock constitutes a well-defined mass, occupying large areas on both sides of Loch Etive, and the mapping in Sheet 53 to the north has shown that it is almost completely surrounded by the granite of Ben Cruachan type.

It includes an area of approximately 60 square miles, and is only covered to an insignificant degree by morainic material or other superficial accumulations. It is characterised by a wild and imposing type of mountain scenery, embracing no less than five peaks more than 3000 feet in height. The ground occupied by this more acid type of rock is more rugged and more heather-covered than the Ben Cruachan area, which is characterised rather by steep grassy slopes, and without extensive areas of bare rock, except in the higher parts of the hills and corries.

As a rule, a fairly sharp boundary line between the two granites is traceable. Occasionally, however, there appears to be a passage between the two—as, for instance, along the eastern flanks of Ben Sguliaird and to the north of Loch Dochard. In the former locality the two types of granite are scarcely distinguishable from one another over a belt of about 20 yards in breadth. In other places, however, the line appears perfectly sharp, and small veins of the acid type are seen to protrude into the Ben Cruachan type. In many parts of Glen Kinglass, especially about Aclarn, the Cruachan granite assumes a well-marked foliated or gneissic structure close to the margin of the coarser, more acid type. This structure may possibly have been induced by the intrusion of the Glen Etive granite before the Ben Cruachan granite had been completely consolidated.

On passing from the Ben Cruachan type to that of Glen Etive and the Blackmount, we notice a fairly abrupt change from a medium-grained rock, often rich in hornblende and plagioclase, to a very coarse and conspicuously porphyritic type of granite, in which the hornblende is greatly diminished, while quartz is frequently conspicuous. This latter rock is evidently of more acid composition than the normal Ben Cruachan granite. It is a hornblende-granite, showing large white and flesh-coloured crystals of felspar, often quite an inch in length, porphyritic, in a coarse granitic ground-mass consisting of orthoclase, plagioclase, and quartz, with some elongated crystals of dark green hornblende and biotite plates.

The coarsely porphyritic structure which is everywhere so conspicuous of the margin is, however, not a uniform feature. The porphyritic crystals gradually die out towards the inner portion of



the mass, so that the porphyritic structure is in this case only a marginal feature. There is, in fact, a coarsely porphyritic marginal zone to this later type of granite, varying from about a quarter of a mile to a mile in breadth. Within this zone lies a generally coarse, homogeneous, pinkish biotite-granite, with hornblende as an occasional accessory constituent. The rock often resembles the more acid pink variety of Ben Cruachan, and there are occasionally, as, for instance, on Ben Starav, considerable variations in texture.

Specimens of this Glen Etive or Blackmount type of granite from the Glen Kinglass area were examined under the microscope. A coarse variety from near Doire-nan-Saor was found to show zoned plagioclase, biotite, and interstitial alkali-felspar in large plates, while quartz was comparatively scarce. Hornblende, sphene, and iron-ores occur as accessories. The interstitial felspar is often developed as micropertthite. Other sections of the rock show a good deal more quartz and sometimes rather less biotite, though on the whole only comparatively slight variation in composition is to be observed in this type of granite.

Fine-grained varieties are found on the upper part of Ben Starav, and on the ridges and corries on its south side, but the constituents are the same as in the coarser varieties. The alkali-felspar occasionally shows microcline structure. A fine-grained grey rock from Coire-nan-Lair, on the south side of Ben Starav, shows porphyritic or pseudo-porphyritic constituents in a finer-grained matrix. The larger constituents comprise zoned plagioclase, micropertthite, quartz, and biotite, while the ground-mass is a micro-crystalline aggregate of quartz and felspar. Small veins and bands, fine-grained, and consisting mainly of quartz and felspar, are not uncommon in certain places. Quartz veins with hollow centres and veins of coarse pegmatite are also met with about Ben Starav and Ben Trilleachan.

A noteworthy feature in connection with these two granite masses is the fact that the Ben Cruachan type of granite is nearly everywhere traversed by numerous dykes of porphyrite and quartz-porphyry, while these intrusions are entirely absent from the inner mass of Glen Etive and the Blackmount. These dykes are exceedingly numerous in the Ben Cruachan area on the south-west side of the Glen Etive mass, and again are equally plentiful in the Cruachan type of granite to the north-east in Sheet 53. This fact alone is suggestive of a later date of intrusion for the inner mass. Throughout the entire area of the Glen Etive granite only one small porphyrite dyke has been observed, and this occurs near the margin of the mass in Glen Kinglass. With this exception, the only dykes found cutting the Glen Etive granite are some peculiar basic types occurring in the Ben Starav area, and these will be described in the following chapter, together with the porphyrites and quartz-porphyries. It is possible that the majority of the porphyrites were intruded into the Ben Cruachan area before the intrusion of the Glen Etive



granite; or, on the other hand, they may have been later than both granites, the fissuring which afforded them an escape upwards being mainly confined to the area peripheral to the central and more plug-like granitic mass.

The variation observed in the Glen Etive granite is mainly one of texture, while mineralogical differences are far less pronounced than in the Ben Cruachan type. The relationship, however, between the two masses is so close that it is evident that they have had a common magmatic origin and belong to the same general period of intrusion.

A characteristic of the ground occupied by the Glen Etive granite is the comparatively extensive area of bare rock actually seen at the surface and practically devoid of any covering of heather or grass. Large tracts of bare rock are thus seen in the Ben Starav and Ben Trilleachan areas and on the north side of Stob Coir an Albannaich, further east. The finer-grained rock is often much disintegrated, and, being split up by close parallel joint planes, forms thick talus-slopes on the hillsides. The coarse type of granite weathers freely over the upper portions of the hills, so as to form a fine quartzose sand overlying the bare rock, and frequently along the exposed ridges large blocks of granite weather out with a rounded form so as to resemble boulders. This is well seen on Stob an Duine Ruaidh, Ben nan Aighean, and Stob Coir an Albaunaich. The northern and north-eastern faces of the mountains are, as a general rule, much steeper than the southern and south-western slopes, and are frequently marked by abrupt lines of precipitous crags. A similar feature characterises the hills of the Ben Cruachan range to the south, though here, owing to the harder and less easily disintegrated character of the rock, the summit ridges are usually sharper and narrower. The pink variety of the Cruachan granite, however, resembles some parts of the Glen Etive mass, and appears to yield, under the influence of atmospheric agencies, more rapidly than the more basic grey granite. It tends to form more or less rounded and hummocky surfaces, while the grey rock stands out in bold crags.

Well-marked vertical combined with horizontal joint-planes are conspicuous about the summit of Ben Cruachan, and give the rocks a roughly mural or rudely castellated appearance; or, frequently, when a set of strong parallel joint-planes lies at an angle to the vertical, the structure of the rock mass assumes a deceptive resemblance to inclined bedding. This "pseudo-bedded" structure is well seen on the northern and north-eastern faces of Ben Cruachan, and in many of the small burns running down the north side into Glen Noe.

*Outlying Masses associated with the Ben Cruachan Granite.*—Two masses of granite of Ben Cruachan type are seen in the extreme north-east corner of the map, in the neighbourhood of Clais-gobhair. These have already been described above. It remains to give some account of the smaller outlying intrusions which are found to the east of the large granite mass of Ben

Cruachan and Glen Etive. These consist of different varieties of diorite, and the rock seen on the west side of Glen Orchy, recently described under the name of kentallenite.\*

In connection with the smaller granite masses in the north-east corner of the map, there occur two small intrusions of diorite. One of these is seen to lie within the granite mass to the north-west of Clais-gobhair. It is an oval-shaped mass of coarse hornblendic diorite, and appears to represent a basic modification of the larger mass within which it occurs. It varies from a fairly coarse rock, containing about equal proportions of hornblende and plagioclase, to a coarse hornblende-rock in which scarcely any felspar is visible to the naked eye. The former variety is seen under the microscope [8621] to be in a great measure made up of large plates of green hornblende, which include small idiomorphic plagioclases and some small flakes of altered and ragged biotite. A few small pyroxene grains are also present, while hornblende and plagioclase also occur interstitially between the large plates of hornblende. There is no quartz. The other intrusion of diorite lies about a quarter of a mile to the north-east, just outside the margin of the granite. It is a similar type of rock to that above described, and the proportion of felspar to ferro-magnesian constituents is apparently more uniform.

Passing further south to the area about the head of Glen Strae, an elongated dyke-like intrusion of dioritic affinities is seen in the flaggy quartzose schists of Meall an Laoigh. A short distance to the west of this intrusion two smaller dyke-like masses of the same type are seen. These three intrusions are specially of interest, as they appear to be of a composite nature and show an interesting type of differentiation.

The marginal portion consists of a black porphyritic rock, showing phenocrysts of augite and pseudomorphs after olivine in a dark compact matrix. This passes into a medium-grained dioritic rock, consisting mainly of hornblende, felspar, biotite, and idiomorphic augite. The central portion is a hornblende-lamprophyre of a type by no means common in this district. The passage between the two kinds of rock is somewhat sudden, yet the lamprophyre can scarcely be regarded as a distinct intrusion, as it has no fine-grained margin, and the characteristic idiomorphic augites of the diorite are still seen to occur in the lamprophyric rock, though less abundantly. The lamprophyre frequently veins the diorite in an intricate manner, and the two types are often so intermingled that they can hardly be otherwise regarded than as portions of one and the same mass.

The basic rock forming the marginal portion of these intrusions shows under the microscope [8944] phenocrysts of idiomorphic augite and pseudomorphs after olivine in a microcrystalline ground-mass, consisting of lath-shaped plagioclase,

\* See Hill and Kynaston—"Kentallenite and its relations to other Igneous Rocks in Argyllshire," *Quart. Jour. Geol. Soc.*, vol. lvi. (1900), pp. 531-557, pls. xxix.-xxxi.

small greenish (? pyroxene) granules, and interstitial matter possibly including some alkali-felspar and accessory magnetite. The pseudomorphs after olivine illustrate the amphibole type of alteration of that mineral. They consist of a fine felted aggregate of colourless amphibole needles, sometimes associated with iron-ore, and are usually surrounded by a border of green fibrous amphibole, often mixed with colourless needles. A similar alteration product after olivine is seen at the margin of a picrite which occurs in Glen Orchy, and which will be described below. It is probably similar to the "pilitite" of Becke.\* This marginal phase has affinities with certain basic lamprophyres and with certain varieties of the kentallenite, to be shortly described.

A specimen from the dioritic portion of these intrusions shows under the microscope [8622] large pale greenish porphyritic augites, with well-defined crystal outlines and a zonal structure which is well seen between crossed nicols. Marginally the augites are partially replaced by greenish hornblende. The rest of the section is dioritic in appearance, and consists of plagioclase, green hornblende, biotite, and some accessory magnetite. The biotite appears in scattered flakes, groups of which are often in optical continuity, an appearance which is due to the biotite being moulded upon the felspars. The plagioclase is mostly idiomorphic, and there would appear to be also a certain amount of interstitial alkali-felspar. In some sections [8945] an occasional accessory pseudomorph after olivine is seen. Some sphene is also present.

The central portion of each intrusion, however, is a rock, as already remarked, of slightly more acid composition, consisting essentially of elongated prisms of greenish-brown hornblende and alkali-felspar, with accessory plagioclase [8946]. The alkali-felspar consists of a granular aggregate, and forms the ground-mass in which the idiomorphic hornblendes lie embedded.

A similar structure is seen in some of the Cornish minettes described by Collins,† in which the matrix that encloses the other constituents is a coarse-grained aggregate of unstriated felspar. This variety of the Meall an Laoigh rock may be classed as a vogesite, hornblende being the predominant ferro-magnesian mineral. Sphene and apatite are accessory, and pseudomorphs of hornblende after idiomorphic augite also occasionally occur. The intimate association of a rock of this type with augite-diorite, in the same intrusion, is strong evidence of the close relationships which undoubtedly exist in the district between the diorites and the lamprophyres. In the further descriptions of these outlying intrusions these genetic connections will still be found to hold good, not only for the lamprophyres and diorites, but also for the kentallenites and other associated rocks.

Augite-diorites showing close affinities to that of Meall an Laoigh occur on the high ground on the west side of Glen Strae,

\* Teall—*Brit. Petrol.*, p. 86, and Rosenbusch and Iddings—*Microscopic Physiography*, p. 217, and pl. xix., fig. 2.

† See Teall—*Brit. Petrol.*, pp. 355-357



and are exposed on the north side of Meall Copagach and on the east side of Beinn Lurachan. The intrusion of Beinn Lurachan is roughly circular in outline, and nearly half a mile in diameter, while the two intrusions on the north side of Meall Copagach are more dyke-like in behaviour. These intrusions closely resemble one another in composition and show very little variation. They consist of an augite-diorite resembling some of the rocks associated with the granites of the Southern Uplands. A hand specimen shows numerous idiomorphic crystals of dark greenish augite in a pale feldspathic ground-mass. The augite is mostly in short, stumpy prisms, and gives the rock, at first sight, a spotted appearance somewhat like that of forellenstein. Biotite is present in small patches and plates, but is not conspicuous. Under the microscope the augite resembles that of the Meall an Laoigh rock, and is frequently partially, and sometimes entirely, replaced by green hornblende [7760, 7761]. Hornblende is also seen to occur as an original constituent, and to be of a variety similar to that observed in the granite and diorite of Ben Cruachan. The rest of the rock consists of biotite, plagioclase, orthoclase, and quartz. The biotite occurs in ragged patches and groups of detached flakes in optical continuity, a feature already noticed as characteristic of the biotite in the Meall an Laoigh rock, and also occurring in the kentallenites. It is of later formation than the plagioclase, which is markedly idiomorphic. The alkali-felspar and quartz are interstitial, and there is a larger proportion of the former present in these rocks than in the Meall an Laoigh diorite.

Somewhat similar diorites occur at no great distance from the margin of the granite of Ballachulish, where they have been mapped by Mr. Grant Wilson.\* This type of augite-diorite is not known to occur anywhere within the granite mass, but only as intrusions in the schists not far from the granite margin. It evidently represents a more basic modification from the same magma, and indicates a marginal type of differentiation.

*The Kentallenite of Glen Orchy.*—On the west side of Glen Orchy, about a mile north of Catinnis and 7 miles from Dalmally, there occur an elongated mass and two smaller oval patches of a basic rock of a dark, almost black, colour. A similar type of rock to that here exposed was originally described from Kentallen, near Ballachulish, and from the neighbourhood of Ben Bhuidhe in the Annual Reports of the Geological Survey, under the name olivine-monzonite; but reasons have been given in the paper by Messrs. Hill and Kynaston, already referred to, for discarding this term in favour of a new one, and the term *Kentallenite* is now generally used, the rock from Kentallen, near Ballachulish, being taken as the type. The principal exposure of this rock in Glen Orchy constitutes an elongated mass almost a mile in length and an eighth of a mile in breadth. It is a medium-grained or coarse massive rock, in which the chief constituents, olivine, augite, biotite, and felspar, are easily seen

\* *Ann. Rep. Geol. Sur.* for 1896, pp. 21, 22.



with the naked eye. The coarser rock forms the greater part of the mass, and weathers into characteristic cup-shaped hollows. Thus a weathered block or boulder may frequently be seen to be pitted or honeycombed all over with hollows up to 9 or 10 inches in diameter, and often resembling the smaller potholes seen in the bed of a stream. These hollows will hold rain-water and growths of moss and lichen, and so tend to assist the chemical action which doubtless such growths largely contributed in starting. (Plate VI.) Huge rugged blocks generally mark the outcrop of the intrusion. The rock has a rusty brown crust, but is almost black when freshly fractured.

A section from the main mass of the Glen Orchy rock shows the following features under the microscope [8614]:—The olivine is seen to occur mostly in rounded grains and seldom to show any well-defined crystal outlines. It is fairly fresh, is traversed by numerous anastomosing veins of magnetite, and often occurs as inclusions in the augite. Augite and olivine appear to be present in about equal proportions, and together with biotite make up perhaps the larger proportion of the rock. The augite chiefly occurs as comparatively large individuals with well-defined crystal outline, and frequently showing a marked zonal structure between the crossed nicols. It also appears in smaller grains and granular aggregates of irregular shape scattered throughout the section. The biotite is strongly dichroic and occurs in ragged plates and patches, and several detached flakes are often seen to be in optical continuity, a feature which has already been noticed in connection with the biotite of the augite-diorites. The interspaces between the larger individuals are filled up by felspar, together with some biotite and small grains of augite. Both orthoclase and plagioclase are present in approximately equal proportions, the plagioclase being perhaps slightly in excess. The plagioclase is distinctly idiomorphic, while the alkali-felspar is interstitial and plays the role of ground-mass. Magnetite fills the veins in the olivine, and appears also as small grains associated with both the olivine and the biotite.

Such are the petrological features of the rock forming the greater part of the Glen Orchy intrusion. A detailed examination, however, of the section exposed in the stream which cuts through the mass shows that it is by no means of uniform composition throughout.

The lowermost portion of the mass is seen to consist of a coarse dark green hornblende-pierite. At its lower margin this pierite exhibits a marginal modification resembling a basic lamprophyre, while at its upper margin it passes somewhat abruptly into the kentallenite in such a way that no very sharp line of demarcation can be traced between the two, nor any well-marked transitional phase. The lower portion of the kentallenite is, however, rather more basic than the normal type, showing very little felspar, and a high proportion of augite and olivine, with a very coarse texture. Followed upwards in the burn-section this type passes

into the normal rock, which again shades into a rather less basic and slightly finer-grained variety towards the upper margin of the mass. The variation throughout the intrusion is thus well-marked, and in a vertical direction. The upper portions of the mass, as in the carboniferous picrite of Blackburn, Linlithgowshire, are the more acid, while the more basic minerals have tended to concentrate in the lower part, and have consolidated as a layer of ultra-basic rock.

Under the microscope [9009] the picrite is seen to consist essentially of olivine, hornblende, augite, and biotite. Only a very minute and insignificant quantity of felspar is occasionally to be seen interstitially. Magnetite is accessory, but chiefly occurs in connection with the alteration of the olivine. The olivine is fairly plentiful in rounded grains. The hornblende varies from brown to greenish, or is sometimes almost colourless, the various gradations of colour being often visible in the same individual; it occurs in large irregular poikilitic plates, which enclose both the olivine and augite. The pleochroism is not very strong. Occasionally the hornblende seems to form a marginal outgrowth to the augite, and may perhaps be partially formed at its expense. The augite is colourless or almost so, and seldom shows crystal form. The biotite is of a deep orange-brown variety, and strongly dichroic. It is of later formation than the hornblende. Felspar is rare, but occasionally occurs in small interstitial patches, without any signs of twinning. This is somewhat suggestive of orthoclase, since we know that the plagioclase of the closely-associated kentallenite crystallised out before the biotite, and the orthoclase last of all interstitially.

The order of consolidation of the minerals in the picrite is—olivine, augite, hornblende, biotite, and finally felspar. Towards its lower margin the picrite becomes finer grained and shows affinities to the basic lamprophyres, while vein-like streaks and patches rich in felspar are not uncommon. The microscope shows [9007, 9008] this marginal portion of the mass to be rich in hornblende, while the proportion of olivine and augite has considerably diminished. The hornblende is green and greenish-brown, and occurs in idiomorphic prisms, frequently giving a lath-shaped section, as in the hornblende-lamprophyres. The augite is considerably altered and sometimes pseudomorphosed. The olivine is represented by pseudomorphs of colourless amphibole needles and magnetite, and secondary green hornblende needles often form a peripheral border to the pseudomorphs. Some biotite is present in small flakes, and sometimes small grains of sphene. Felspar is fairly plentiful and resembles that of the lamprophyres, occurring as small plagioclase crystals with good idiomorphism. A small quantity of interstitial quartz is also present. Patches rich in felspar are also seen, and are somewhat coarser than the surrounding rock, but graduate imperceptibly into it. They consist of idiomorphic plagioclase and micropegmatite. The lower margin of the picrite thus presents a peculiar modification of more acid composition, allied to the lamprophyres.

Passing to the upper part of the picrite mass, we find, as we approach the kentallenite, that the rock becomes slightly coarser, and the microscope shows [9010] that the hornblende has diminished while the proportion of augite has increased, the hornblende usually being confined to the marginal portion of the augites. The proportion of felspar, however, does not appear to have perceptibly increased.

The next phase of the mass that is exposed is a basic form of the kentallenite, showing a low proportion of the feldspars and occasionally a small quantity of pale green hornblende [9011]. In the typical kentallenite, which succeeds this phase, the hornblende has entirely disappeared, and the biotite is of a browner colour, and does not show the rich orange tinge characteristic of that mineral in the picrite. The upper margin of the kentallenite does not assume a particularly fine-grained aspect, but appears to become slightly more acid and to show an approach to lamprophyre.

Occasionally within the normal type of kentallenite we find inclusions consisting of roughly spheroidal masses, up to two feet or more in diameter, consisting of a finer-grained type of kentallenite. These masses show well-formed olivines and augites in a ground-mass consisting of biotite, plagioclase, and alkali-felspar. There is a sharp distinction between the ground-mass of biotite and felspar and the relatively large and conspicuous augites and olivines, the biotite and felspar being not nearly so coarse as in the normal rock. The augite and olivine apparently represent the first generation of crystallisation, while the felspar and biotite would appear to represent a second generation of more rapid crystallisation.

In one place the kentallenite is seen to be traversed by a narrow vein of very coarse white felspar and large biotite plates, doubtless analogous to the pegmatite veins so common in certain granites, and consisting, as is also the case with granite pegmatite, of these constituents of the parent rock which were the last to crystallise out from the intruded magma.

Some interesting inclusions may be observed in the picrite. Ignoring occasional fragments of quartzite, these are of two kinds:—(1) Mushroom-shaped inclusions, 6 inches or so in diameter, of fine-grained kentallenite, and (2) nodular lumps, a few inches in diameter, of a fine-grained dark greenish rock resembling certain lamprophyres, and showing conspicuous phenocrysts of hornblende. The rock of the mushroom-shaped inclusions consists [9013] of relatively large, idiomorphic, zoned augites and olivines, in a fine-grained ground-mass of felspar, with elongated, irregular strips of biotite and small pyroxene granules. It, thus, in many respects resembles the rock composing the spheroidal inclusions in the kentallenite. The other inclusions consist of large brown and greenish hornblendes resembling the hornblende of the picrite, in a micro-crystalline and rather peculiar ground-mass. This ground-mass is not uniform in composition; some parts, though rather obscured by



decomposition, appear to consist of plagioclase and orthoclase with some scattered hornblende needles, while other parts are rich in alkali-felspar and crowded with small colourless grains and crystals of pyroxene. Some sphene, apatite, and magnetite are also present. It is not easy to explain these inclusions; they may perhaps represent magmatic concretions or consolidations of an earlier phase. That they are intimately and genetically connected with the mass in which they are found, their petrological composition and affinities sufficiently show, and they would appear to indicate a certain amount of intermingling of the various products of the differentiation of the present magma. They afford, moreover, an interesting link in the chain of evidence which indicates a common origin for the picrites, kentallenites, and lamprophyres.

If we compare the kentallenite with the augite-diorites, already described, associated with the marginal area of the Ben Cruachan granite, it is evident that there are close petrological affinities between the two. In the case, for instance, of the augite-diorite of Meall an Laoigh, the addition of olivine and the elimination of the hornblende would give us a rock closely resembling the kentallenite of Glen Orchy. The augite is similar in both rocks, and the biotite has a similar mode of behaviour, while interstitial orthoclase is a characteristic feature. Moreover, the evidence of the inter-relationships of all these outlying intrusions, and their relation to the granite, is perhaps still more complete in the area about Glen Fyne and Ben Bhuidhe to the south-east, for here we have an intrusion consisting partly of kentallenite and partly of augite-diorite, and in another part of the same area we find a direct passage between augite-diorite, allied to kentallenite, and biotite-granite. (The majority of these intrusions occur in Sheet 37 to the south, and are described in the Explanation dealing with that sheet.) We thus have a series of intrusions consisting of picrite, kentallenite, augite-diorite, and lamprophyre, which may be shown to be so closely related to one another by common petrological characters and mode of occurrence that we must conclude that they were derived, by some process of differentiation, from a common magma. Furthermore, the evidence, not only from the Ben Cruachan area, but also from the other areas where a similar assemblage of intrusions occurs, points to the fact that these outlying intrusions constitute basic modifications of the same general magma from which the larger masses of granite and diorite were derived. The entire evidence on this head has been discussed at length in the paper already referred to, and to this the reader is referred for further information on this subject.

The numerous dykes and sills which cut not only the Ben Cruachan granite, but traverse the surrounding country in great numbers, may similarly be shown to be closely allied to one another, and to have close genetic relationships with the granite. These will be described in the following chapter.



*The Altered Rock, allied to Porphyrite, of the South-eastern Spurs of Ben Cruachan.*—Before leaving the Ben Cruachan area, it is necessary to give some description of a remarkable mass of rock which occupies a well-marked belt in the south-eastern portion of the Ben Cruachan range. This mass has an elongated form slightly over four miles in length, and measuring half a mile at its maximum breadth. It stretches from the ridge of Meall Cuanail (2200 feet), situated about half a mile due south of the summit of Ben Cruachan, in an almost due easterly direction to Coire Cruachan (1200 feet), and thence, still in an easterly direction, to the summit of Beinn-a-Bhuiridh (2941 feet), where it attains its greatest breadth. On the north side of Beinn-a-Bhuiridh precipitous crags of at least 800 feet in height are formed entirely of this rock. From Beinn-a-Bhuiridh the mass takes a more north-easterly trend, and is well seen in Allt Coire Ghlas and Allt Coire Creachan, descending to a level of 500 feet. Further to the north-east the rock appears in Allt Mhoile at slightly over 400 feet, and then rises sharply to 1930 feet on the ridge separating Beinn Eunaich from Stob Maol, and thins out to a narrow strip slightly further on. We thus see that this rock-mass traverses elevated ridges and deep corries alike; it goes up one side of a ridge and down the other side in a manner strongly suggesting the behaviour of a great vertical dyke-like mass. The total vertical thickness of this mass exposed is not less than 2500 feet, while its maximum breadth is half a mile. The mass is bounded almost entirely by the granitic and dioritic rocks of the Ben Cruachan range. Thus, on its south and south-east sides we have the diorite and hornblende-granite of the lower slopes of Beinn-a-Bhuiridh and Monadh Driseag, while on its north side the more acid type of the Ben Cruachan granite is in contact with it. It is only for a short distance at its north-eastern end that the rock is in contact with the older metamorphic rocks. The whole of the western portion of the mass consists of a rock frequently closely resembling that of some of the porphyrite dykes, and is of a dark grey or dark greenish colour. In Allt Coire Ghlas, Allt Coire Creachan, Allt Mhoile, and in the intervening ground, however, the rock loses its porphyrite-like appearance and assumes a schistose structure. But no line can be drawn between the two phases, the normal structure of a fine-grained porphyritic rock, resembling porphyrite or andesite, appearing gradually to pass into a structure indistinguishable from that of a thoroughly foliated rock. At its north-eastern extremity, however, to the north of Stob Maol, no schistose structure can be detected, and the rock again assumes the appearance of a porphyrite. The planes of schistosity in the foliated portion are vertical or almost so, and lie parallel to the general line of elongation of the mass. The rock has evidently been altered by the granite of Ben Cruachan and shows contact phenomena, which may be well seen under the microscope. The presence of this alteration, combined

with the foliated structure which has been super-induced upon a considerable portion of the mass, has rendered the investigation of the original nature and relationships of these rocks a matter of great difficulty. The foliated rocks, with their frequent plagioclase phenocrysts, suggested, at first, affinities to some of the older metamorphic rocks such as the schistose epidiorites; but the fact that the microscopic features and composition of these rocks did not recall those of any of the older epidiorites, and that the greater portion of the mass showed no signs whatever of foliation, seemed to render this view improbable, and to suggest affinities rather with the later series of andesites, porphyrites, and diorites.

A large series of specimens has been collected from all parts of this interesting mass and examined under the microscope, and the evidence of this examination is extremely suggestive in connection with the relations of the rock-mass as a whole.

It will be convenient, first of all, to deal with those parts of the mass which show no marked signs of any foliated structure. This includes the larger proportion of the mass, though it cannot be said that here a tendency to some parallel structure is invariably absent. We have, as it were, occasional transitions or tendencies to the schistose structure, indistinguishable from the flow structure of a normal andesite or porphyrite, and it is probable that such structures are in fact largely due to fluxion movements in the original magma. A large portion of the rock, however, shows no signs of any movement of any kind whatever.

The hand specimens of the majority of the altered rocks from the unfoliated portions have a remarkable resemblance to altered andesites. They are various shades of grey and sometimes greenish-grey in colour, but the more highly altered rocks near the granite are pale grey, while the least altered are very dark. This feature has been found to be very characteristic of the alteration of andesitic rocks by a large mass of granite, and is exemplified both in the Cheviot area and in the alteration of the andesites of the Glencoe series by the Blackmount granite.\*

The microscopic examination of these rocks shows that they consist for the most part of contact-altered augite and hornblende andesites, and diorite-porphyrates. On the whole they have strong affinities with porphyritic intrusive rocks of the porphyrite and andesite types. A specimen of an altered augite-andesite was collected from the extreme north-eastern portion of the mass. It consists [9311] of phenocrysts of plagioclase and augite, the latter for the most part altered into pale green uraltic hornblende, in a ground-mass of rather trachytic structure formed mainly of small lath-shaped plagioclases. Some small flakes of pale green hornblende, possibly secondary, are scattered about, but there is very little secondary biotite. In the ferromagnesian phenocrysts the form of the original augite crystal is often well seen, and occasionally some epidote is associated with their alteration. A little sphene is also present. It is doubtful

\* See *Summ. Prog. Geol. Sur.* for 1900, p. 82.

if there was any original hornblende present. This rock shows considerably less alteration than is usually observed in the mass, but a specimen, collected by Mr. J. B. Hill, from the Allt Coire Glas burn shows even less, and is remarkably fresh. It is closely allied to the pyroxene-bearing hornblende-andesites.

Under the microscope [9267] one sees porphyritic augites and a few phenocrysts of clear plagioclase. The augite is of a very pale greenish colour when fresh, and is partly altered into green fibrous urallite. Numerous small prisms of original, and fresh, brown hornblende are also present, giving the characteristic rhombic cross-sections with truncated acute angles and lath-shaped vertical sections. Both larger and smaller sizes are seen. These hornblendes are of the same type as those so characteristic of the hornblende-andesites, but without the resorption border so commonly observed in these rocks. The ground-mass consists mainly of small lath-shaped plagioclases, with an arrangement indicating flow structure, small hornblendes, interstitial matter, and accessory magnetite. This rock shows several points of resemblance to the pyroxene-hornblende-andesite of the north side of the Clach Leathad in the Blackmount; it also has very much the aspect of some of the newer porphyrites.

In the less-altered types the ground-mass is usually of the felspar-lath type, and shows a high though varying proportion of small lath-shaped plagioclases. In one of the specimens, however, there seems to have been a considerable proportion of originally glassy base. This occurs near the foot of Allt Coire Ghlas, and the rock has a very strong resemblance to a normal andesite. Under the microscope a section of this rock [9038] shows crystals and crystalline groups of plagioclase, with characteristic inclusions of the ground-mass, and some altered hornblendes, in a ground-mass which was possibly originally glassy and now has a greyish-brown dusty appearance, with paler aureoles round the ferromagnesian phenocrysts. Apatite and magnetite are accessory. The plagioclase has a peculiar greyish cloudy appearance, frequently seen in contact altered andesites. The hornblendes are rather decomposed, but appear to be now represented almost entirely by aggregates of small biotite flakes, green hornblende, and magnetite. Some of the patches look as if augite had been originally present.

In the more altered specimens the ground-mass appears to have been completely reconstructed, and consists of a clear granular mosaic of felspar and quartz, throughout which numerous flakes of secondary biotite, of the contact type, and green hornblende lie scattered. Apatite is almost invariably an accessory, and sometimes small grains of sphene. In no case does the alteration appear to have gone so far as to have had any very marked effect upon the felspar phenocrysts, though they usually show the peculiar cloudy appearance already noticed. They are frequently honeycombed with inclusions of the ground-mass in a characteristic manner [9317, &c.].



The proportion of phenocrysts to matrix varies very considerably, some bands of the mass being so rich in phenocrysts as to resemble a diorite. Indeed, it is sometimes difficult in the field to distinguish these rocks from the dioritic phase of the Ben Cruachan granite which is in contact with the southern margin of the mass. Under the microscope these varieties, rich in phenocrysts, show strong affinities to many of the later porphyrites. They occur on the west side of Coire Cruachan, on Beinn-a-Bhuiridh, and in the Allt Mhoile burn. A specimen from the latter locality [8865] has strongly the appearance of a porphyrite which has undergone contact metamorphism. It contains numerous phenocrysts of plagioclase and greenish uralitic hornblende, probably after augite, in a ground-mass consisting of a micro-crystalline aggregate of felspar, quartz, and granules of green hornblende. Apatite is accessory. The ground-mass is crowded with patches and aggregates of small flakes of secondary biotite. Some sphene is also present. In another specimen of the same variety from the west side of Coire Cruachan [9313] the ground-mass is rather of the felspar-lath type. These rocks were probably originally augite-porphyrites, or some closely allied variety. The augite is now, as a rule, almost entirely replaced by a pale green, often fibrous, hornblende (uralite), which often behaves as a distinct individual with the general outline of the original augite crystal, but is sometimes broken up into a granular aggregate. Occasionally the original unaltered pyroxene is seen remaining as a core surrounded by the secondary hornblende [8611].

Original hornblende, probably of the brown variety, was evidently present in many of the rocks. It has now been replaced by aggregates of secondary biotite flakes, grains of green hornblende, and magnetite. A similar type of alteration has been described in the case of the Blackmount andesites.\* Occasionally the original form of the hornblende crystal is still preserved [9312, &c.], but more often it has become completely lost and is represented by an irregular patch of the secondary minerals. Original biotite has only been observed for certain in one specimen [9314]. Flow structure is very common, and by becoming more and more marked appears sometimes to graduate imperceptibly into the more schistose type of structure which characterises the north-eastern portion of the mass.

Vesicular varieties are sometimes met with [9315], and sometimes the ground-mass contains irregular patches and streaks of clear crystalline quartz. Some of these patches may represent vesicles, or some may be included fragments of quartzite, since in certain parts of the mass, especially in the crags on the west side of Coire Cruachan, fragments of pale quartzite up to 4 or 5 inches in diameter has been observed.

We will now pass on to the schistose or foliated varieties of the mass, which occur, as already pointed out, in its north-eastern or narrower portion. In dealing with these rocks we find that they

\* See *Summ. Prog. Geol. Sur.* for 1900, pp. 82, 83.



consist of precisely the same minerals as are found in the main portion of the mass, already described, and the plagioclase phenocrysts may still be frequently recognised. The majority of the rocks have the appearance of fine-grained biotite-augen-gneisses or hornblende-biotite-gneisses, the relative proportions of hornblende and biotite varying considerably. The phenocrysts are sometimes somewhat scarce, but occasionally are very numerous, as was also seen to be the case in the unmoved portion of the mass. Granulitic and cataclastic structures may frequently be observed, but often the schistose appearance seems to be due rather to a fluxion-foliation structure. The schistose structure is perhaps best developed among the rocks exposed in the Allt Mhoile and Allt Coire Creachan burns and in the intervening crags. It is also strongly developed along the northern margin of the mass, on the north side of Beinn-a-Bhuiridh, but dies out rapidly as one enters the main mass of Beinn-a-Bhuiridh. Specimens from Lairig Torran, on the north side of Beinn-a-Bhuiridh, shows a well-marked gneissic structure. Sections from these and from a large number of other specimens were examined under the microscope by Dr. J. S. Flett, and the following notes are partly taken from his descriptions.

The rock exposed at Lairig Torran is gneissic in structure, and shows well-marked granulitic and cataclastic features under the microscope [7627, 7628]. Porphyritic feldspars and occasionally quartzes are present and often tend to form lenticular augen. Sometimes the phenocrysts show signs of bending and fracture. The matrix is granulitic and streams past the phenocrysts; it consists of feldspar, quartz, green hornblende, and biotite. The granulitisation, however, is not of an advanced type. Mere fluxion, with or without contact-action, would hardly have been sufficient to give the rock its present structure. There has evidently been shearing as well.

In the Allt Mhoile burn and in the crags above it we find fine-grained grey gneissose rocks. These show under the microscope [8258-8260] comparatively large and more or less turbid phenocrysts of plagioclase, often with irregular borders, in a ground-mass of granular quartz and feldspar, hornblende and biotite, with sphene and iron-ores as accessories. There are also some patches of green hornblende, which are often micro-poikilitic. Occasionally [8259] augite is seen as cores in the hornblende.

These examples will give a good idea of the structure and composition of the schistose portion of the mass. The rocks evidently show varying degrees of granulitisation and shearing, together with structures indicating fluxion foliation. These rocks certainly do not represent the ordinary types of the schistose epidiorites—that is to say, the metamorphic igneous rocks of earlier date than the general foliation of the Highlands. But we know that these so-called epidiorites vary in composition and metamorphism, and one might quite well suppose that these rocks belonged to some acid type of schistose epidiorite in which the metamorphism was of a comparatively low degree, if one were to judge by the aspect and character of these particular specimens

alone. Neither are they usual types of the newer intrusives. Some are good biotite-gneisses. There can be no doubt about the cataclastic structures in some, while others show a fluxion-foliation due to movement during consolidation. The effects of contact-action in these gneissic types are doubtful and obscure, but these are not rocks that would lend themselves easily to contact alteration.

These schistose varieties, however, belong to the same series, and form part of the same mass, as the porphyrite and andesite-like varieties already described; and these latter constitute the greater part of the mass and show strong affinities to the later diorite-porphyrates and andesites. It would appear, then, by no means improbable that the whole mass belongs to the newer series of intrusives.

In that case, the development of the gneissose facies is of great interest. The intrusion of the mass evidently took place prior to that of the Ben Cruachan granite, but probably, from the evidence of its belonging to the later intrusives, during the same geological period. The movements which caused the foliation structures were of a local character, and probably affected a portion of the mass previous to its complete consolidation, continuing to a certain extent after consolidation was complete, and thus producing the shearing and cataclastic structures observed. This mechanical action may possibly have been connected with the movements which accompanied, or immediately preceded, the intrusion of the enormous mass of the Ben Cruachan granite.

As regards the unfoliated portion of the mass, the petrological evidence already brought forward of its close relationships to the newer intrusives would seem to be sufficiently clear. Apart, however, from an examination of the rocks by themselves, this relationship is brought out in a remarkable manner, if we compare the altered porphyrites on the south side of Beinn-a-Bhuiridh, from the marginal part of the mass, with the marginal portion of the Beinn-a-Bhuiridh diorite which is in contact with them, and which is a modification of the Ben Cruachan granite. This diorite passes at its margin into a diorite-porphyrate, and a section of this shows [9613] so many characters in common with the altered porphyrite adjacent to it [9614-9616] that one might almost take the two facies as representing different portions of the same mass. The structure and composition are the same, and the majority of the constituents of a similar type, and the same alteration of the pyroxene to uralite is seen in both. The high proportion, however, of secondary biotite flakes, of a contact type, seen in the altered porphyrites is always characteristic and distinctive. Apart from this feature the rocks are practically the same.

The gneissic facies is analogous to the foliated Galloway granites. Thus a portion of the Criffel granite shows a facies resulting from mechanical deformation, which varies in structure from gneissose to granulitic.\* Moreover, the field evidence shows

\* See *The Silurian Rocks of Great Britain*, vol. i., pp. 609, 610.

that the movement took place after the rock had reached its present position, and after the formation of the acid veins, and probably before the cooling was quite complete. The microscope shows that the last-formed minerals, namely, the alkali-felspar and the quartz, yielded most to the deforming stresses, and the ferro-magnesian minerals form well-marked flaser. In its more extreme phase the rock loses its gneissose character and passes into a grey granulite; the secondary micro-crystalline aggregate forms a large proportion of the main mass, and cataclastic structures are strongly marked.

Well-marked granulitic structures are also occasionally produced by contact-action in the Silurian volcanic rocks of the same region by the larger basic masses, and banded granulitic rocks have been formed in the volcanic zone surrounding the Cheviot granite close to its contact with the andesites on the southern margin of the mass. But, although contact metamorphism is thus capable of producing the granulitic structure by a process of reconstruction and recrystallisation of the constituents, it is not probable that this has been the only factor in the formation of the peculiar granulitic types of the Ben Cruachan district. We must have had here in addition the operation of considerable mechanical stresses analogous to those which affected the granite of Criffel. It is of great interest, therefore, to be able to note the action of such deforming forces at a period later than that of the formation of the Highland schists, which has produced structures almost identical with those found in those older rocks.

ii. *The Glen Fyne Granite and Outlying Masses.*—A small portion of the Glen Fyne granite is seen to enter the extreme south-east corner of the map. It occupies the hill-slopes on the east side of Glen Fyne and crosses the river just below Inverchorachan, but does not extend any great distance on its west side. This granite constitutes a continuation of the igneous mass of Garabal Hill and Meall Breac, described by Messrs. Dakyns and Teall.\*

The character of the rock which enters the present sheet is that of a hornblende-biotite-granite of fairly coarse grain, and good exposures may be studied in the bed of the River Fyne below Inverchorachan. The granite is of an acid type and contains sphene, and bears a strong resemblance to the coarse acid type of hornblende-granite which constitutes so large a proportion of the large granite mass of Glen Etive to the north of Ben Cruachan. Vein-like intrusions of a very similar type of granite are common on the steep slopes on the western side of Glen Fyne.

Further to the west, on the ridge of Beinn Bhuidhe, a small mass of granite occurs between the summit of Beinn Bhuidhe and Stac-a-Chuirn. This intrusion has an irregular, more or less crescent-shaped form at the surface. It crosses the ridge and is seen for a short distance on the steep craggy slopes on either side of it. Another smaller mass of granite occurs on the

\* *Quart. Journ. Geol. Soc.*, vol. xlviii. (1892), p. 104.



north-west slopes of Beinn Bhuidhe. These granites are of medium grain and of rather acid type, resembling some of the finer-grained portions of the Glen Fyne intrusion. They are undoubtedly closely related to the far larger mass of Glen Fyne, and constitute subordinate modifications of the same magma. These granites represent the more acid intrusions of the Beinn Bhuidhe complex, the basic intrusions being represented by the kentallenites of Allt an t-Sithein and the Brannie Burn. A transitional series of diorites also occurs, but these do not come within the area of the present sheet, and so are described in the Explanation for Sheet 37 to the south. We will therefore proceed to give a short description of the kentallenites and compare them with the kentallenite of Glen Orchy, described above.

*The Kentallenites of Allt an t-Sithein and Brannie Burn.*—About  $2\frac{1}{2}$  miles west of Beinn Bhuidhe a roughly oval-shaped intrusion of kentallenite occurs in the Allt an t-Sithein Burn. The longer diameter of the mass is rather over a quarter of a mile in length. Its mode of occurrence and manner of weathering is exactly similar to the intrusion of Glen Orchy. A similar intrusion, though perhaps slightly larger in size, is exposed near the head of the Brannie Burn, about one mile S.S.W. of Beinn Bhuidhe. These two masses closely resemble one another in composition, but are slightly different from the rock of Glen Orchy. They are rich in pyroxene, but do not contain quite so high a proportion of olivine as the Glen Orchy rock, while, on the other hand, the proportion of the feldspars, and especially of orthoclase, to the olivine and pyroxene is decidedly higher. Of the two masses that of the Brannie Burn would seem to be slightly the more basic. The augite does not exhibit crystal form anything like so perfectly as in the Glen Orchy rock, but tends to occur rather as corroded grains and granular aggregates. The characteristic ophitic structure of the biotite constitutes a pronounced feature in the Brannie rock [7414].

In a section of the An t-Sithein rock [7415] the proportion of olivine is relatively small. The rock, however, is rich in pyroxene, and shows frequently a slightly pleochroic hypersthene in association with the augite. But the most characteristic feature of both these rocks is the orthoclase. In the Brannie rock it occurs in approximately equal proportions with the plagioclase, but in the An t-Sithein rock it is decidedly in excess. It is poikilitic in appearance, and forms a matrix of comparatively large, clear, irregular patches, in which small, lath-shaped, idiomorphic plagioclases lie embedded unorientated. With respect to the olivine and pyroxene the orthoclase is interstitial. Individual patches occasionally show twinning on the Carlsbad plan. We see then in these Beinn Bhuidhe rocks the same peculiar features as have already been noticed in the kentallenite of Glen Orchy. The rocks are especially remarkable for their high proportion of orthoclase, in association with minerals such as olivine, augite, and hypersthene.



The Allt an t-Sithein mass exhibits a certain amount of variation in the course of the section exposed in the burn, but to a less degree than is seen in the mass of Glen Orchy. Slightly below the intrusion of typical kentallenite in the Allt-an t-Sithein, and separated from it by a band of schist, we find an intrusion, a few yards in breadth, of a medium-grained black rock resembling in hand specimen a basic lamprophyre rather than kentallenite. From its microscopic characters, however, it would appear to be a variety of kentallenite, poor in olivine, but closely related to the normal type of the intrusion exposed a few yards from it. Under the microscope this rock [9290] is seen to consist essentially of augite, hypersthene, biotite, plagioclase, and orthoclase. Olivine also occurs, but is scarce and forms rather an accessory than an essential constituent. It is usually enclosed in the augite and is considerably altered. A small quantity of interstitial quartz is also seen. Some greenish hornblende is frequently associated with the peripheral portions of the augites. The hypersthene is markedly pleochroic. The orthoclase occurs in relatively large micro-poikilitic patches, as in the more normal kentallenite. It shows Carlsbad twinning, and is perhaps slightly in excess of the plagioclase. The rock is not a typical kentallenite, though closely allied to it. It might perhaps be termed a hypersthene-kentallenite.

The lower margin of this intrusion represents a slightly more acid modification, and resembles a mica-diorite. A section [9289] shows a few decomposed idiomorphic augites, biotite, idiomorphic plagioclase, orthoclase, and quartz. The two latter sometimes form micro-pegmatite. There is also some sphene. A pale green hornblende, chlorite, calcite, apatite, and magnetite occur as accessories. The biotite is moulded on the plagioclase, as in kentallenite. The rock, however, is more acid than the central part of the intrusion, and shows affinities with the augite-diorites. This intrusion is separated from the main mass of the kentallenite by a narrow belt of schist. The main mass shows no variation in composition worth noticing. Bands of finer-grained material occasionally occur, in which the idiomorphic augites may be clearly seen with the naked eye. The upper margin of the mass is also slightly finer-grained. Hypersthene occurs throughout.

The intrusion of the Brannie Burn is only partially seen in the present sheet, the lower portion being included in Sheet 37. It should be pointed out, however, in this connection that the lowermost portion of this intrusion, as in the case of the Glen Orchy mass, consists of a coarse greenish black picrite, which is seen for about 15 yards in the burn section. It consists [9293] of olivine, augite, and some hypersthene, resembling that of the kentallenite, together with biotite and a little interstitial plagioclase. It differs, therefore, from the Glen Orchy picrite in the presence of accessory hypersthene, and in containing no hornblende. A small quantity of hypersthene is also frequently present in the Brannie kentallenite [9294, 9295].

In the Beinn Bhuidhe area, as already pointed out, similar relationships have been found to hold good between the kentallenites, diorites, lamprophyres, and the granites as are found in the Ben Cruachan area.

As regards the chemical composition of these kentallenites, an analysis of the rock of Kentallen, near Ballachulish, was published in the Annual Report of the Geological Survey for 1896, p. 22. More recently an analysis of the Allt an t-Sithein rock was made by Dr. W. Pollard, of the Geological Survey, and published in the paper on the kentallenites already referred to. The complete analysis of this latter rock is as follows:—

|                                      | Per cent. |            |
|--------------------------------------|-----------|------------|
| SiO <sub>2</sub> - - -               | 52.09     | } = 100.24 |
| TiO <sub>2</sub> - - -               | .73       |            |
| Al <sub>2</sub> O <sub>3</sub> - - - | 11.93     |            |
| Cr <sub>2</sub> O <sub>3</sub> - - - | .10       |            |
| Fe <sub>2</sub> O <sub>3</sub> - - - | 1.84      |            |
| FeO - - -                            | 7.11      |            |
| MnO - - -                            | .15       |            |
| (CoNi)O - - -                        | .07       |            |
| CaO - - -                            | 7.84      |            |
| MgO - - -                            | 12.48     |            |
| K <sub>2</sub> O - - -               | 3.01      |            |
| Na <sub>2</sub> O - - -              | 2.04      |            |
| CO <sub>2</sub> - - -                | .16       |            |
| P <sub>2</sub> O <sub>5</sub> - - -  | .34       |            |
| Cl - - -                             | trace     |            |
| H <sub>2</sub> O (105°) - -          | .11       |            |
| H <sub>2</sub> O (above 105°) -      | .24       |            |

Specific gravity = 2.94.

The result of the above analysis fully bears out the observations made from the microscopic examination of the rock sections. The presence of chromic oxide probably indicates the occurrence of a small quantity of chromite or picotite, which is known to be of common occurrence in rocks rich in olivine, though it was not detected with certainty under the microscope. If this analysis is compared with that of the rock of Kentallen, it will be seen that the Beinn Bhuidhe rock is the more acid of the two, the Kentallen rock containing 48.49 per cent. of silica. Moreover, the magnesia percentage of the latter rock rises to 15.26, thereby showing a closer affinity to the picrites than the Beinn Bhuidhe rocks. The total alkalis are slightly higher in the Kentallen rock, but their relative proportion is reversed when we come to the more acid Beinn Bhuidhe rock, which shows the potash in excess of soda, and this one would naturally expect from the relatively high proportion of orthoclase. The analysis, however, fully bears out the petrological evidence that the rocks of Beinn Bhuidhe, Glen Orchy, and Kentallen belong to the same group—a group of rocks with essential olivine and augite, and smaller

amounts of orthoclase and plagioclase in varying relative proportions.

In concluding this account of these peculiar rocks it will perhaps not be out of place to summarise briefly their petrological affinities and relations, a detailed account of which has already appeared in the paper referred to, and from which the following notes are taken.

The kentallenites of Argyllshire constitute one of the few known examples in Britain of the peculiar association of orthoclase with olivine and augite. They show affinities (1) to the picrites, in their high proportion of augite and olivine; (2) to the shonkinites of America (described by Messrs. Weed and Pirsson\*), in the peculiar association of orthoclase-felspar with olivine and augite; and (3) to the monzonites of Prof. Brögger,† more especially to the basic variety of Smålingen in Sweden, in the fact that orthoclase and plagioclase occasionally occur in approximately equal proportions. Besides these examples, we may cite that of the rock of Dignäs, in Norway, described by Brögger‡ as a variety of olivine-gabbro-diabase, and now included in his monzonite group. This rock contains accessory olivine and a small proportion of orthoclase. Moreover, the occurrence of a considerable proportion of a rhombic pyroxene in addition to augite in the Beinn Bhuidhe rocks recalls certain hyperites and norites in which orthoclase frequently occurs in addition to plagioclase, but without the association of olivine. Such are the hyperites, described by Dr. Teall,§ associated with the Loch Dee granite of the Southern Uplands. These rocks show affinities to the so-called norites of Teller and Von John in the neighbourhood of Klausen in the Tyrol, and are essentially composed of plagioclase, hypersthene, augite, and biotite, with small quantities of quartz and orthoclase occurring as interstitial matter. Among the Cortlandt series of the Hudson River the norite proper, described by G. H. Williams,|| consists mainly of andesine and hypersthene, with accessory biotite; but an interesting feature is the occurrence in it of large crystals of orthoclase enclosing the other minerals in a poikilitic manner. This mode of occurrence of the orthoclase is very characteristic of the kentallenites of the Ben Bhuidhe area, also of the shonkinites and the olivine-monzonite of Smålingen. It also behaves in the same way in the monzonites (augite-syenites) of Southern Tyrol.\*\*

\* *Bull. Soc. Geol. Am.*, vol. vi. (1895), pp. 400-422; also *Am. Journ. Sci.*, ser. 3, vol. 1. (1895), pp. 467-477.

† See "Die Eruptionsfolge der Triadischen Eruptivgesteine bei Predazzo in Südtirol," No. ii. of "Die Eruptivgesteine des Kristianiagebietes," Vidensk. Skrift. No. 7 (Kristiania, 1895).

‡ Brögger—"The Eruptive Rocks of Gran," *Quart. Journ. Geol. Soc.*, vol. L., p. 19.

§ *Ann. Rep. Geol. Sur.* for 1896, pp. 41, 42.

|| *Am. Journ. Sci.*, ser. 3, vol. xxxiii. (1887), pp. 135-144, 191-194.

\*\* Brögger—"Die Eruptionsfolge der Triadischen Eruptivgesteine bei Predazzo in Südtirol," pp. 56-57, figs. 1 and 2.



Kentallenites are found not only in the Beinn Bhuidhe and Ben Cruachan areas, but also in two other areas in Argyllshire characterised by large intrusions of granitic and dioritic rocks—namely, the Ballachulish area and the district about Kilmelford and Loch Avich. In each of these areas kentallenite shows the same associations and relationships.

H. K.

*Lismore.*—Four small intrusive masses, which include the rock-types tonalite, syenite, and diorite, occur in the portion of Lismore Island within the sheet. The first forms a small promontory on the west side of the island, nearly half a mile due west of Fennacrochan. It is shown in vertical section in the cliffs and has a conical shape. The rock is a medium to fine-grained quartz-biotite-diorite, containing hornblende as well as augite. At the northern end of the intrusion an interesting melanocratic modification is found. It contains, in addition to groups of large idiomorphic pyroxenes, phenocrysts of serpentine after olivine. This marginal modification resembles kentallenite in the occurrence of orthoclase along with olivine, in the colour and perfect form of the augite, and in the late crystallisation of the biotite.

A second boss, about  $\frac{1}{4}$ -mile broad, rises as a dome-shaped hill to the south-east of the first one, and its boundaries are much obscured by drift. The centre of the intrusion is a medium-grained augite-diorite containing chiefly pink feldspar. In some parts of the intrusion biotite becomes very abundant, and the rock shows dark angular patches consisting of biotite, orthoclase, and plagioclase. These dark patches, though similar to a microlamprophyre in composition, are unlike the lamprophyres which are associated with the diorites and are later than the intrusions. Perhaps they are early consolidated portions of the magma caught up in a still fluid portion which solidified later.

The margin of this intrusion is seen against the contact-altered schists on the shore and is exceedingly complex. The igneous rock sends out strings and veins into the limestone breccia (p. 81), and itself encloses numerous fragments of limestone, which, when weathered out, gives the igneous rock a scoriaceous appearance. Close to the margin the diorite passes into a very fine-grained grey rock curiously similar in appearance to the indurated limestone. Between the diorite mass described above and the beach, a band of dark mottled igneous rock, which is orientated east and west, crops out between the hornfelsed limestone of the aureole of contact alteration and a gravel deposit of the raised beach. It is a syenite, the peculiar character of which is pointed out in the following petrological notes by Dr. Flett (p. 109). The joints in the rock tend to form horizontal columns, and the appearance of the outcrop is suggestive of a dyke.

A third boss-like intrusion of tonalite, about 200 yards broad, occupies the floor of the valley  $\frac{3}{4}$ -mile south-west of Fennacrochan, and is surrounded by high cliffs of altered limestone. On account of the position of the mass, erosion has not proceeded far into it, and a marginal modification is found forming a thin

skin over parts of the outcrop. This modification is very similar to the peculiar syenite mentioned above.

Two small outcrops at the edge of the peat at Sron-na-Craoibhe probably belong to an intrusion otherwise obscured by peat and drift. The limestone shows contact alteration along the edge of the peat. The rock is similar to that described from the boss mentioned above, and it contains fragments of the limestone-schist.

All the rocks are much weathered at the outcrop, but the decomposition probably does not proceed beyond a few feet. Two of the outcrops are situated close to a deep and sheltered natural harbour, but a drawback to the working of these rocks as "granite" on a commercial scale is the variable nature of the rock due to rapid changes in the proportions of the mineral constituents.

H. B. M.

The igneous rocks which occur in the island of Lismore as small bosses and dykes are interesting, because they furnish examples of a variety of types such as usually arise from the newer granites of the West Highlands by processes of differentiation. Some of them also exhibit peculiarities which are by no means common in the district.

The most acid of these rocks are aplites, which form small dykes intersecting the dioritic bosses. They are probably to be regarded as segregations. Their only feature deserving mention is their comparative richness in oligoclase. About  $\frac{3}{4}$ -mile south-west of Fennacrochan there is a mass of tonalite. This rock, which is of medium grain, contains biotite, hornblende, and augite, with plagioclase, orthoclase, and quartz, and is too full of orthoclase to pass as a normal diorite. The hornblende is clear green, as is usual in tonalites; the biotite dark brown and vividly pleochroic; the pale green augite rarely forms independent crystals, but serves as a nucleus for peripheral growths of biotite and hornblende. Graphic or parallel intergrowths of the pyroxene and the amphibole also occur. The augite is often darkened by fine dusty magnetite, and may show a fine parallel lamellation like that commonly seen in diallage. Of the three ferro-magnesian minerals biotite was last to crystallise, and may enclose ophitically the earlier plagioclases. The feldspars of this rock are principally oligoclase and orthoclase, the former having far the more perfect crystalline form. Decomposed, cloudy centres in many of the plagioclase crystals probably indicate the existence of basic cores, but satisfactory optical tests cannot be applied to establish this. Quartz also is present, but in no great amount. The accessory minerals include much brown sphene, apatite, magnetite, and zircon. Some of the zircon crystals are large, pink coloured, slightly pleochroic, and of marked pyramidal habit. This led to a suspicion that they might include xenotime, and some were isolated and tested micro-chemically, but all proved to be zircon.

Syenites are by no means common in any part of the Scottish Highlands, and two rocks of this class which occur in Lismore

are deserving at least of passing notice. One is a pale grey granitoid rock from the surface of the boss situated three-quarters of a mile south-west of Fennacrochan, and consists of perthitic orthoclase, plagioclase (mostly oligoclase), and green chloritic pseudomorphs, presumably after hornblende. It is decomposed, and contains much calcite, but quartz is practically absent from the rock, and in its structures and the relation of its minerals to one another it is a good example of the group to which it belongs. The other is a rock of less normal character, and comes from a dyke-like mass 3 furlongs west by south of Fennacrochan. In the sections the great abundance of pale green augite in idiomorphic crystals is the most striking feature. With these there is much perthitic orthoclase, some plagioclase, but no quartz. Pyrite, magnetite, and a little brown biotite are the principal accessories, with many large and well-formed prisms of apatite. The absence of hornblende and quartz and the scarcity of biotite are remarkable, and give the rock almost a unique character among the differentiation products of the Old Red granites of Scotland.

Diorites seem to be the prevalent rocks of the bosses. They mostly have the hypidiomorphic or true plutonic structure, but in some of their marginal facies the minerals have crystallised in two stages, and diorite porphyrites are the result. Although many of the diorites contain green hornblende they are characterised rather by the abundance of pale-coloured augite and biotite. Of these three minerals the augite is the earliest, and is frequently surrounded by hornblende in parallel growth; in some cases the amphibole may be partly secondary. Some of these rocks contain many large idiomorphic augite crystals, pale green and sometimes zonal, which might quite well be regarded as phenocrysts. In their perfection of outline and in their colour they recall the pyroxenes of the kentallenites. This resemblance is heightened by the occurrence of much biotite, dark chestnut brown changing to clear yellow when the polariser is rotated, and often enclosing numerous small lath-shaped feldspars in ophitic fashion. There are also in some of the slides obscure pseudomorphs which may represent original olivine, so that the affinities of these rocks to the kentallenites is certainly very close. As Messrs. Hill and Kynaston,\* however, have defined kentallenite as consisting of essential olivine and augite with orthoclase, plagioclase, and biotite, these rocks are excluded from the group. That they belong to the facies of the newer granite, which are typically developed only in the Argyllshire province, is at the same time perfectly clear. The amount of alkali-feldspar which they contain in addition to plagioclase is variable, but is usually small.

In Lismore also the lamprophyric dyke rocks of the newer granite series are well represented. They are composed mainly of greenish-brown hornblende with orthoclase and plagioclase. The hornblende is in idiomorphic crystals, and the feldspar also

\* *Quart. Journ. Geol. Soc.*, vol. lvi., p. 540, 1900.



is usually more or less perfectly formed. When orthoclase predominates they belong to the vogesite group; when plagioclase is the principal felspar they are best described as spessartites. Biotite frequently is visible in the sections, and a peculiar dyke from Sron-na-craoibhe is a minette which is very rich in porphyritic crystals of olivine and augite, but this can only be inferred from the outlines of the pseudomorphs after these minerals, since, as is frequently the case in these rocks, the material available for study is so decomposed that minute description is precluded.

Of the later dykes which traverse the island in a west-north-west direction, only one was examined microscopically. It is a compact and fresh rock which might be considered a fine-grained basalt, but contains no olivine, and consequently might equally well be assigned to the andesites. Its essential constituents are plagioclase felspar, brown augite, and magnetite, but occasional phenocrysts of dark brown hornblende are present also, and give the rock a somewhat abnormal character. It may belong to the same group as the dykes mapped by Mr. Bailey on the mainland opposite.

J. S. F.

## CHAPTER IX.

### SILLS AND DYKES.

#### i. THE SERIES ASSOCIATED WITH THE NEWER GRANITE-MASSSES AND LAVA-FLOWS.

A glance at the map will show that an enormous number of sills and dykes traverse the Lorne volcanic plateau, the Ben Cruachan granite, and the neighbouring area of the metamorphic rocks. It will be seen that these intrusions are most numerous over a belt of country, from four to five miles in breadth, extending from the Ben Cruachan area, where it comprises the high ground on both sides of Loch Etive, in a S.S.W. direction as far as the south-west corner of the map. To the north-west of this belt it appears that dykes and sills are comparatively rare, while in the central portion of the large granite tract they are altogether absent. To the east of Loch Awe the intrusions belonging to this later series are likewise not merely so numerous as further west, but appear to increase in the area about the head of Glen Shira. To the north of the Strath of Orchy they occur here and there throughout the region of the flaggy quartzose schists, and become more numerous in the granite mass of Ben Cruachan facies, in the north-east corner of the map.

These intrusions have a general N.N.E. and S.S.W. trend, and this feature is especially well seen throughout the belt above referred to, in which they attain their maximum development. This trend is maintained irrespectively of the nature of the rock in which the intrusion occurs, but it would appear to be closely related to the trend of the planes of cleavage and schistosity in the metamorphic rocks. In the eastern portion of the area, however, as we go further from the granite mass, the trend of the dykes and sills frequently varies considerably, an east and west trend being sometimes observed, and sometimes a single intrusion may have a more or less sinuous course.

By far the larger number of the dykes and sills consist of porphyrites, and rocks of more or less intermediate composition closely allied to them, and these types are best developed in the great zone of intrusions stretching from the south-west corner of the map to the Ben Cruachan granite. Together with these we occasionally get quartz-porphyrries, micro-granites, diorites, and lamprophyres. The lamprophyres, however, are best developed in the more outlying portions of the area. They are most common in the region between the head of Loch Awe and Glen Fyne, and are especially numerous in the area about Glen Shira. All these intrusions show close genetic relationships to one

another, and the various allied types are connected with one another by intermediate varieties. They show on the whole the same relationships to one another as has already been shown to exist in the larger igneous masses. They represent, with some few exceptions, the latest phase of the intrusive activity of Lower Old Red Sandstone times.

We will now give a more detailed account of these intrusions, commencing with the more acid types.

(1 *Quartz-Porphyries*. — Dykes of quartz-porphyry are of somewhat common occurrence in the Ben Cruachan granite on both sides of Loch Etive, especially in the neighbourhood of Bonawe. These usually consist of a matrix which is sometimes granophyric and sometimes micro-crystalline or micro-granitic, and which encloses phenocrysts of orthoclase, plagioclase, and quartz, the latter occurring frequently in doubly-terminated crystals. Occasionally phenocrysts of biotite may also be detected, and in one case the alkali-felspar was found to be fresh and sanidine-like [7606].

In the metamorphic area quartz-porphyries have been observed about three miles north-east of Kilchrenan, and occasionally on the north-east side of the Pass of Brander. They are also of common occurrence in the area of flaggy quartz-schists about the head of Glen Stræ.

In the volcanic area they are somewhat rare, but have been observed cutting the andesitic lava flows close to Gorstain, south-west of Taynuilt, and again on the south side of Glen Loran. These closely resemble the dykes found associated with the Ben Cruachan granite, the dyke from near Gorstain consisting of phenocrysts of quartz, felspar, and biotite, in a micro-poikilitic ground-mass of felspar and quartz, which forms small halos around the phenocrysts. In the Benderloch area sills intermediate between quartz-felsites and porphyrites cut the andesites on the south side of Beinn Lora. Occasionally an intrusion has been seen to consist partly of quartz-porphyry and partly of porphyrite, the two types appearing to pass gradually into one another. A good example of this is seen a mile and a half west of Taynuilt, where a portion of a large porphyrite dyke is evidently of more acid composition, and is seen to contain numerous phenocrysts of quartz, but no sharp line can be drawn between the two. On the other hand, however, quartz-porphyry may sometimes be seen to be intrusive in the porphyrites. Thus, on the southern side of Beinn Duirinnis, a dyke of quartz-porphyry lies for a considerable distance in contact with a porphyrite, and in one place small tongues of the quartz-porphyry are seen to be intruded into the porphyrite. There can be no doubt, however, that there is no great difference in the age of any of these intrusions, and that they all belong to essentially the same general period of intrusion.

(2 *Porphyrites*. — The dykes and sills of porphyrite and closely-allied varieties are best developed in the zone, already



referred to, which stretches from the Ben Cruachan granite to the south-west corner of the map. They are again seen in some numbers in the north-east corner, whence they are continued with a similar trend into Sheets 53 and 54. In describing these rocks the term porphyrite will be used in its more recent sense, as employed, for instance, by Dr. Teall in his description of the dykes associated with the Criffel and Dalbeattie granite masses. We may therefore define porphyrite as a rock of intermediate composition representing the dyke phase of an andesitic magma. The essential porphyritic constituents are plagioclase felspar and a ferro-magnesian mineral such as biotite, hornblende, and occasionally augite.

These sills and dykes traverse the Ben Cruachan granite, the lava-flows of Lorne, and the metamorphic rocks. They may be traced from the Lorne plateau on the south-west side of the Pass of Brander, across the River Awe, and thence through the intervening zone of metamorphic rocks into the granite of Ben Cruachan.

Throughout the whole area in which they occur these rocks maintain a similar petrological facies, though frequently in the granitic area they have the appearance of having consolidated at a greater depth. The intrusions vary from a few feet to 30 yards or more in breadth, and a single dyke or sill will often show very considerable variations in breadth, and may sometimes be seen to die out somewhat abruptly. Two dykes may sometimes occupy the same fissure and thus form a compound intrusion. The trend of the dykes is often remarkably straight for considerable distances, but, on the other hand, it may often diverge considerably from the normal, or assume a sinuous or winding course. Branching dykes are common, and such branches may occasionally anastomose with neighbouring intrusions. This feature is often seen among the dykes on the north side of the Pass of Brander.

In the granite area the large majority of the porphyrites constitute well-marked dykes, sills being commoner in the Lorne plateau and in the metamorphic area. They belong for the most part to the hornblende- and biotite-porphyrites. They contain phenocrysts of idiomorphic plagioclase, hornblende, and biotite, while orthoclase and quartz are only rarely present as porphyritic individuals, usually being only found in those rocks which constitute intermediate varieties between the porphyrites and the quartz-porphyries. The rocks vary in colour from dark grey to almost brick-red, the latter tint, however, being probably merely due to decomposition. The proportion of ground-mass to phenocrysts varies considerably, some varieties containing phenocrysts in such numbers as at first sight to resemble granites, others again showing only a very small proportion of porphyritic constituents. Plagioclase, usually oligoclase, is always the most conspicuous phenocryst, occurring as simple crystals and groups. Biotite is perhaps the commoner ferro-magnesian mineral, and may occur either with or without hornblende, while in some

types the hornblende predominates. The ground-mass may be micro- or crypto-crystalline, while in some cases a tendency to the micro-graphic structure may be observed. Sometimes the structure may be seen with the naked eye to be of a fine-grained granitic type, so that one might almost call the rock, in such cases, a granite-porphyr. These sills and dykes would probably show on analysis very little difference in composition from the normal type of the Ben Cruachan granite, the structural differences between the two being probably due merely to variation in the conditions of consolidation of the original magma which was their common source of supply.

The numerous porphyrite intrusions show considerable variability both in texture and composition. Perhaps the commonest and most typical variety is a hornblende-biotite-porphyr, but every variety of rock may be encountered which will unite this type with the quartz-porphyr, on the one hand, and with the diorites on the other hand. Thus, starting with the biotite-bearing quartz-porphyr, an increase in the proportion of the plagioclase felspar with a diminution of the orthoclase and quartz gives us a quartz-biotite-porphyr, and a slightly more basic modification of this variety brings us to the normal type of the biotite-porphyr. The addition of hornblende gives hornblende-biotite-porphyr. In structure these latter, especially in the case of the larger intrusions, are often intermediate between porphyrite and diorite, and a transition from these varieties to typical diorites is of common occurrence, and sphene, in these as well as in the dioritic phase of the Cruachan granite, is a common accessory. Similarly numerous connecting links may be found between the diorites and the hornblende-lamprophyres. Thus, just as in the main mass of the granitic rocks every variety may be found between an acid granite and a diorite, so among the numerous dykes and sills we have transitional varieties connecting granite-porphyr and quartz-porphyr on the one hand, and fine-grained diorites and hornblende-porphyr on the other hand. In short, such strong affinities appear to be thus indicated between the dykes and sills and the granite that we may feel fairly confident in asserting that they have both been derived from the same common magma, and the variation in the injections shows that differentiation had already proceeded in the magma to a considerable degree previous to its intrusion.

Before passing on to the other types of dyke- and sill-rock, it will be of interest to describe briefly the microscopic characters of some of the more interesting varieties of the porphyrites.

Some good examples of the more acid varieties are found in the neighbourhood of Clais-gobhair, in the Blackmount. A specimen from Meall Bhuidhe, to the east of the upper portion of Glen Kinglass, shows abundant phenocrysts of felspar, biotite, hornblende, and small quartz grains in a fine greyish matrix. Under the microscope [8624] all the larger phenocrysts of felspar are seen to consist of plagioclase, and to be in excess of ortho-

clase, which occurs here and there in smaller crystals. Quartz occurs sparingly in small, rounded grains. The biotite occurs as plates with ragged outline, and is also scattered throughout the rock in groups and patches of small flakes. These groups are frequently associated with the hornblende, and would appear to be replacing it owing to some secondary action. The hornblende is pale green and occurs in irregular patches and grains, without any crystal outline, and the patches appear as a granular aggregate between crossed nicols. Occasionally these patches have a fairly well-defined form, but they are always associated with numerous small flakes of biotite and grains of magnetite. Apparently there has been a gradual breaking down of the hornblende, and it is now partially replaced by secondary biotite and magnetite. The original biotite and hornblende both occasionally occur as inclusions in the felspar. The ground-mass is a micro-crystalline quartzo-felspathic aggregate with small disseminated grains of biotite and hornblende. Magnetite is accessory.

Another variety of hornblende-porphyrity, with acid tendencies, is common in the Ben Cruachan granite on the ridge to the west of Stob Ghabhar, near Clais-gobhair. The felspar phenocrysts sometimes range up to an inch in length, while elongated crystals of hornblende and plates of biotite are easily seen with the naked eye. The microscope shows [8623] that some of the felspar phenocrysts are orthoclase, though the larger proportion are plagioclase. The hornblende is fresh and occurs in well-defined elongated prisms. The biotite occurs in about the same proportion as the hornblende, and frequently as plates with hexagonal outlines. Quartz occurs as an accessory, but is not visible to the naked eye, and only appears in occasional small rounded grains. The ground-mass is micro-crystalline. It shows much idiomorphic plagioclase, small greenish hornblendes, and biotite, with interstitial felspar and quartz. This latter variety appears to have closer affinities with the Glen Etive type of granite than with that of Ben Cruachan.

Another example from the Blackmount is a hornblende-porphyrity with affinities to hornblende-andesite. It shows [9020] phenocrysts of clear plagioclase, hornblende, and biotite. The plagioclase is often zoned, sometimes shows pericline twinning, and occasionally encloses the hornblende and biotite. The hornblende is fresh, idiomorphic, and of the brown variety. Some pale green fibrous (uralitic) hornblende also occurs, which may possibly represent augite. The ground-mass is micro-crystalline, and consists of small idiomorphic plagioclases, small biotite flakes, interstitial quartz, and possibly also some alkali-felspar. Sphene, apatite, and magnetite are accessories.

Varieties more basic than the normal have sometimes been met with as intrusions in the Lorne volcanic area. Thus, in the Kilchrenan area, one of the sills of normal porphyryite consists in part of a basic modification which shows phenocrysts of plagioclase.



clase, brown hornblende, and malacolite, in a ground-mass of lath-shaped plagioclases, chlorite, and iron-ores [7632].

A good example of one of the basic types of porphyrite occurs on the west side of Glen Nant, and may be termed a hypersthene-diorite-porphyrte. It contains [9652] numerous phenocrysts of well-formed zonal plagioclase, with perhaps also some orthoclase in addition, idiomorphic hypersthene weathered to bastite, and a pale greenish augite, still mostly fresh. The ground-mass is granular, and consists of hypidiomorphic plagioclase, with some alkali-felspar and a little quartz. There are small granophyric halos of micro-pegmatite around the feldspars of the ground-mass. Apatite and magnetite are accessory. A somewhat similar rock occurs further to the south-west, on the north side of Lochan Dubha. It consists of phenocrysts of idiomorphic plagioclase, hypersthene, and augite, in a ground-mass of lath-shaped plagioclases, granular augite, biotite, and magnetite. These more basic varieties apparently have affinities with the hypersthene-andesites on the one hand, and with the hyperite phase of the diorites on the other hand. By a diminution of the more basic constituents they pass gradually into the normal types of porphyrite.

Other varieties again, by a diminution of the plagioclase phenocrysts and an increase in the proportion of the hornblende, show affinities with the hornblende-lamprophyres.

(3) *The Lamprophyres and Diorites.*—The lamprophyres constitute a rather ill-defined group, which shade off on the one hand into the porphyrites and on the other hand into the diorites. They occur chiefly as dykes, and sometimes as sills. They are distributed over the entire area comprised in the present sheet, but are not nearly so numerous as the porphyrites, and tend rather to occupy the more outlying portions of the area in respect of the granite mass of Ben Cruachan. An occasional lamprophyre, it is true, cuts the Ben Cruachan granite, and a peculiar basic variety occurs in the more central mass of Glen Etive, but, apart from these instances, the intrusions of this group occur mainly in the metamorphic area in the eastern and south-eastern portion of the map. They are especially numerous in the Glen Shira and Beinn Bhuidhe district, and here perhaps belong rather to the intrusions associated with the Glen Fyne granite than to those associated with the Ben Cruachan mass. To the south-west of the Pass of Brander lamprophyres are of comparatively rare occurrence in the Lorne volcanic rocks and in the metamorphic area on the north-west side of Loch Awe. Outside the north-west margin of the Ben Cruachan granite an occasional lamprophyre is seen in the area about Glen Creran.

As a rule, the lamprophyres are fairly uniform in their behaviour and maintain a similar trend to that of the porphyrites. They frequently, however, deviate from the normal north-east and south-west trend, and in the area about the head of Glen Shira are often seen to traverse the schists in almost any direction. The intrusions seldom attain so great a breadth as



the porphyrites, nor, as a rule, can they be traced for so great a distance, and they frequently vary in breadth from place to place.

The lamprophyres constitute a series showing a considerable amount of variation. Frequently they are highly micaceous, and resemble typical mica-traps or minettes, and these pass imperceptibly into other types containing a large proportion of hornblende. These hornblende-lamprophyres constitute the commonest type of the district, and frequently show transitions to fine-grained diorites. More basic types also are of not unfrequent occurrence, which show affinities to the kentallenites and augite-diorites already described.

In the Ben Cruachan area intrusions which may be classed with the lamprophyres only rarely occur. An occasional dyke, however, allied to the diorite-porphyrites may be seen cutting the granite on the south side of Beinn Duirinnis, above the Bonawe quarries. Specimens from these rocks show under the microscope [7612] large aggregates of hornblende crystals in a ground-mass consisting mainly of hornblende needles, idiomorphic plagioclase, and iron-ores. In the central mass of Glen Etive some peculiar basic dykes occur, with a general north-west and south-east trend, which perhaps belong to basic types of lamprophyre. They are narrow dykes, only a few feet in breadth, of a black rock usually considerably decomposed. A specimen from Coire nan Lair, on the south side of Ben Starav, shows under the microscope [7762] green pseudomorphs after olivine, abundant idiomorphic augite, brown basaltic hornblende, biotite of the same colour as the hornblende, felspar (scarce), magnetite, and some undetermined interstitial matter. The hornblende in these rocks is identical with that which occurs in the camptonites, and the rocks as a whole show strong affinities to the camptonites and monchiquites. It is interesting to find such basic rocks of this class cutting the later and more acid phase of the granite, and it is probable that they represent basic modifications of the underlying magma, intruded during the later portion of the dyke-forming period.

Basic types of lamprophyre, though considerably less basic than the above, are also met with in the metamorphic area between the head of Loch Awe and Glen Fyne. A basic sill of this type is well seen about a mile S.S.E. of Dalmally. It is a dark grey, almost black, medium-grained rock. Under the microscope [8464, 8861, 8862] it is seen to show affinities to some of the basic augite-diorites, allied to kentallenite. It is exceedingly rich in pyroxene, while the proportions of biotite and plagioclase seem to vary in different parts of the sill. The augite is almost colourless and frequently shows good idiomorphism. Besides the augite there are also some pseudomorphs which appear to represent olivine. There is no hornblende. The biotite occurs mostly in irregularly-shaped, elongated flakes, which are seen to be moulded upon the plagioclase and to be therefore of later formation. The plagioclase occurs occasionally

as idiomorphic porphyritic individuals, which are usually rather decomposed, but mostly as more or less lath-shaped individuals in the ground-mass. Interstitially there is a small amount of quartz, and a very small quantity of alkali-felspar may also be present. Occasionally one sees an interstitial substance bordering some of the plagioclase crystals, and showing a micro-structure suggestive of micro-pegmatite.

Again, two small lamprophyre intrusions of a basic type occur on the slopes of Ceann Garbh, about two miles north-east of Beinn Bhuidhe. These sills are similar in appearance, and consist of a medium-grained dark grey rock, in which augite and some plagioclase may be seen to occur porphyritically. Under the microscope [7416 and 7417] a section is seen to consist of fairly numerous and relatively large phenocrysts of augite, and a few of plagioclase, in a ground-mass which is mainly feldspathic. The augite is idiomorphic, colourless, and frequently shows a well-marked zonal structure. The ground-mass consists mainly of small lath-shaped plagioclases, small augite grains, irregular flakes of biotite, and chloritic alteration products. There is a very small quantity of interstitial quartz, and magnetite is accessory. These rocks also have close affinities with the augite-diorites of the same district.

Between these basic lamprophyres, rich in augite and the more normal type of hornblende-lamprophyre, various intermediate varieties occur. Thus in some of the intrusions the proportion of augite is comparatively small, while a brownish hornblende, of the type characteristic of the camptonites and spessartites, makes its appearance, and the proportion of plagioclase increases. A sill occurring about a mile north of Meall nan Tigearn illustrates this transition. A section shows [8834] a few chloritic pseudomorphs after augite, brown hornblende in elongated prisms, more or less idiomorphic plagioclase, and a small quantity of interstitial quartz. The proportion of biotite varies greatly in these sills, but its absence is unusual. With the increase of the proportion of the hornblende the augite disappears, and we have varieties of hornblende-lamprophyre which constitute the commoner type of this class of intrusion. In many of these hornblende is often porphyritic, and by the advent of plagioclase phenocrysts and an increase in the felspar of the ground-mass, they pass over into the hornblende-porphyrates.

It is difficult, however, to adopt any systematic classification for the lamprophyres of this district, since owing partly to their inherent variety, partly to the great readiness with which they decompose, and partly to their propensity to develop distinct facies in different parts of their course, it is not easy to say exactly to what sub-division any particular example is to be assigned. Apart from the example already described which occurs in the Glen Etive granite, it does not appear that any true camptonites (in the sense employed by Rosenbusch) occur in this district. The commoner types of lamprophyre, consisting

essentially of plagioclase and hornblende, may be termed spessartite, and when biotite occurs in addition to the hornblende we have biotite-spessartites, and the augite-bearing types, some of which have already been noticed, may in the same way be referred to as augite-spessartites and augite-biotite-spessartites. At the same time, it will be understood that transitional varieties between these types are common, and that any one variety may sometimes pass into another even in the course of a single intrusion. The essential minerals, biotite, brown hornblende, plagioclase, and orthoclase, are often all present in the same specimen, and may occur in any relative proportion.

Lamprophyres of the plagioclase-hornblende series, or spessartite type, are certainly the most typical and widespread of the district. Members of the orthoclase-bearing series, such as minettes and vogesites, are comparatively rare. The intrusions are, therefore, more representative of a granite-diorite magma rather than a syenitic.

A good example of what may be termed a typical spessartite occurs on the north side of Glen Orchy, N.N.W. of Inverlochry, near Dalmally. It is seen under the microscope [8615] to contain abundant idiomorphic brown hornblendes in elongated crystals, idiomorphic plagioclase, with some interstitial orthoclase and quartz, and accessory magnetite. Sills and dykes of this type are common in Glen Shira, Glen Orchy, and on Beinn na Sroine, between Glen Orchy and Glen Lochy. These rocks have been previously described in some of the Annual Summaries of the Geological Survey as camptonites, but, for the reasons already given, it is considered here more advisable to refer to them as spessartites. A varying proportion of biotite usually occurs in addition to the brown hornblende, and occasionally the former mineral may be in excess of the latter, in which case the rocks may be classed rather with the kersantites. A dyke of this latter type is seen to cut the andesitic lava-flows of Lorne, one and a half miles N.N.E. of the head of Loch Scamadale. It contains [10134] a high proportion of biotite; the feldspars are decomposed, but consist largely of plagioclase, with some interstitial quartz and micro-pegmatite. There are also some pseudomorphs of chlorite, possibly after pyroxene.

A characteristic peculiarity of some of the lamprophyres is the occasional occurrence in them of xenocrysts and xenoliths. We may thus sometimes find rounded crystals of feldspar or quartz, and occasionally rounded fragments of the rock which the lamprophyre has traversed. A small lamprophyre dyke, occurring on the west side of Glen Creran, shows this peculiarity in a marked degree. The weathered face is seen to be thickly studded with quartzite fragments, and in places the rock is so full of these fragments as to resemble a breccia. The fragments are sometimes rounded, but often angular. The marginal portion of the dyke is a breccia consisting of lamprophyre and shattered quartzite. A similar phenomenon has been noted by Mr. Grant Wilson in some of the intrusions in Glen Orchy and



in Glen Suileag in the Loch Eil district.\* The dyke in Glen Creran only appears at the surface for about 100 yards, and disappears below the quartzite at either end. Possibly the abundance of fragments may be explained by supposing them to represent portions torn from the walls of the fissure, and carried upwards by the lamprophyre magma, so that they would tend to accumulate towards the limit of its intrusion.

As regards the age of the lamprophyres, it is evident from their genetic relationships that they belong to the same period as the porphyrites and quartz-porphyrtes, and are also closely associated with the larger intrusions of diorite and kentalenite. The majority of the intrusions of porphyrite, &c., are clearly later than the large masses of granite, and the same may also be said of some of the lamprophyres, as we sometimes find them also cutting the granite. It is probable, however, that some, on the other hand, are of earlier date than the granite, as in the Beinn Bhuidhe district we find a lamprophyre cut by a vein of granite close to the main mass of the Beinn Bhuidhe granite. The microscope shows that distinct contact alteration has taken place in the lamprophyre. Thus, a section taken close to the contact with the granite vein shows that the lamprophyre now consists essentially of small scales of contact brown mica and water-clear plagioclase [8467]. Slightly further from the vein there are still signs of contact action, though the original crystals and crystalline aggregates of hornblende may be well seen [8468]. Dr. Teall, who has examined these sections, remarks that these specimens seem to remove all doubt as to the contact-metamorphism of the lamprophyres. It is probable, therefore, that the lamprophyres of this district represent different phases of intrusion acting at different periods during the general intrusive activity of the area.

In addition to the different types of lamprophyre already described, we also find occasional dykes that should rather be described as diorites than lamprophyres. These occur principally in the Glen Orchy area, and in the region between Glen Orchy and the great mass of granite to the west. Although referred to as diorites, these rocks are frequently of decidedly lamprophyric type, and in many cases are of the same composition as the spessartites, the only difference being that they are coarser in texture. They thus consist essentially of plagioclase and brown or greenish-brown hornblende, with varying proportions of biotite and interstitial quartz and alkali-felspar. Occasionally plagioclase, and sometimes also hornblende in addition, may occur as conspicuous phenocrysts.

A few dyke-like intrusions of augite-diorite have also been observed, as, for instance, on the northern slopes of Meall Copagach, between Glen Strae and Glen Kinglass, which are identical in every respect with the mass of augite-diorite already described above, and occurring in the same part of the area,

\* *Summ. Prog. Geol. Survey* for 1897, p. 66.



slightly further to the east. But all these intrusions are so closely associated genetically with the true lamprophyres that it is evident that they merely represent slightly different phases of the same magma.

Attention has already been drawn to the close connection between the quartz-porphyrines and porphyrites and the large granitic masses. The close association, therefore, of the lamprophyres with the diorites, augite-diorites, and kentallenites falls naturally and consecutively into the same series of phenomena, and serves still further to bind together all these varying intrusions into one connected series. H. K.

*Lismore.* — The lamprophyre dykes on Lismore, though usually having a north-east to south-west trend, are not uniformly orientated like the majority of the dykes connected with the newer granites of Northern Argyllshire. They are irregular, frequently branching, or appearing as a series of lenticular masses placed end to end, and can seldom be traced for any distance. Some small amount of earth-movement seems to have taken place since their injection, as they are frequently broken up. The most frequently occurring type of rock is a dull greenish or brownish fine-grained vogesite, showing to the eye more or less biotite and decomposing hornblende or augite.

A rather different type of vogesite containing long idiomorphic pointed prisms of hornblende is found chiefly on Eilean Ramsay and the neighbouring islets. It forms dykes ten to twelve feet broad, which trend in various directions. The spessartites are represented by a biotite-spessartite dyke intruded into the quartzite at the north end of Eilean Dubh, whilst the mica lamprophyres are represented by the minette from Sron-na-Craoibhe.

The lamprophyre dykes traverse the hornfels zone surrounding the diorite intrusions without being themselves altered, and small veins of lamprophyre were noticed in the diorite itself. Without doubt they belong to the numerous class of dykes which followed the intrusion of the newer granites in Argyllshire. None of the ordinary porphyrite dykes have been found on Lismore, but it has been noticed in other districts that the lamprophyre dykes become relatively abundant as the porphyrites diminish in number at a distance from the large granite masses. H. B. M.

## ii. EAST AND WEST DOLERITES.

This series of intrusions can hardly be said to be very well represented upon the present map. Dykes of the east and west type are perhaps best seen in the neighbourhood of Dalmally. They enter the eastern portion of the sheet in Glen Lochy, and are continued westwards as far as the southern flanks of Ben Cruachan and the Pass of Brander. They occur as far south as

the head of Glen Shira, but do not extend further north than Beinn na Sroine, between Glen Lochy and Glen Orchy.

They constitute broad and well-marked dykes, which may often be followed for considerable distances with a general east and west trend. They occasionally form a depressed feature in the rocks which they traverse, as is seen in the case of the dyke on the southern slopes of Beinn a Bhuidh, but more usually they constitute conspicuous craggy features, so well seen on the hill sides on the north side of the Strath of Orchy. In the Ben Cruachan area these dykes sometimes apparently coincide with lines of east and west dislocation in the granite, and occupy some of the depressions or cols between the more elevated portions of the mountain-ridges.

Petrologically these dykes consist of medium-grained to coarse dolerites. They are never vesicular, as is so often the case with the dolerite dykes of Tertiary age. They are relatively rich in plagioclase, and belong rather to the typical augite dolerites than to the more basic olivine-bearing group.

### iii. TERTIARY DYKES.

The dykes of Tertiary age are entirely confined to the western portion of the map. They are found in Lismore and in the area to the south of Oban. The normal trend of these dykes, unlike those of earlier age, is north-west and south-east, though occasional deviations from the normal direction are not uncommon. In the south-western corner of the map there is a zone of Tertiary intrusions of great complexity. In this zone the dykes are exceedingly numerous and vary greatly in size. They range from basic to acid, and compound intrusions are very common.

*a. Dolerites and Basalts.*—By far the greater proportion of the Tertiary dykes consist of dolerites and basalts. In the district extending from Oban to the area about Loch Scamadale they are exceedingly numerous. They are subject to local augmentations of number, and in some places become so plentiful that it is often difficult to represent them all on the map. The dykes vary in size from two or three feet in breadth, and sometimes even less, up to 50 feet, or sometimes more; the smaller intrusions, however, are by far the more numerous.

In the area about Loch Scamadale and about the head of Loch Feochan, the dykes are often of a more yielding nature than the rocks which they traverse. The material of the dyke decomposes and weathers away more rapidly than the surrounding rocks, so that the site of the dyke forms a narrow cleft or gorge. Such gorges and ravines, due mainly to the disintegration of the basic dykes, are very common on both sides of Loch Scamadale, and are usually occupied by streams flowing down from the higher portions of the hills. The general trend of these dykes is north-west and south-east, but local variations of trend are common, and some of the dykes have often a more or

less sinuous course. The normal trend, again, may sometimes be diverted into a completely different direction along pre-existing lines of faulting. This is well seen in the Eas Ruadh, on the north side of Loch Scamadale, where the Tertiary dykes have been diverted into a north-easterly direction along an older line of fault in the Lorne volcanic rocks.

The larger dykes frequently send off smaller branches into the surrounding rock, or, again, several small neighbouring dykes may sometimes be followed until they unite and form a single intrusion. Compound dykes are of common occurrence, and may sometimes consist of as many as five, six, or even seven separate intrusions running side by side in the same fissure. Many of these compound dykes consist of intrusions differing markedly from one another in composition, and varying from olivine-basalts to acid dykes allied to rhyolite. The more acid intrusions are invariably the younger, and these are frequently seen to split up the more basic. So also in the compound dykes, consisting of thoroughly basic rocks, the more acid varieties almost invariably split up the more basic. These composite dykes will be referred to again in connection with the acid intrusions.

The basic dykes consist of basalts and dolerites of slightly varying composition. They usually contain olivine, but the proportion present varies considerably, some varieties containing a much larger amount than others. The dolerites, in addition to the olivine, contain grains and ophitic plates of augite, the ophitic structure being frequently well developed. Vesicular varieties are also common.

Many of the finer-grained dykes have a spherulitic structure developed along their outer margins, the spherules being frequently as large as peas and often grouped in rows, like those observed by Mr. Clough in Skye. These spherulitic margins are frequently two or three inches in breadth.

Porphyritic varieties are not common in the area described, but have occasionally been met with. H. K.

*Lismore.*—A series of basaltic dykes trend across the island from W.N.W. to E.S.E. or occasionally from west to east, and traverse both the diorite bosses and the lamprophyre dykes. Usually between two and three, but never more than six feet broad, they are both the most numerous and most regular of the dykes. They may often be traced as low grass-covered ridges across the island. They vary from dark bluish compact rocks with a conchoidal or platy fracture to fine-grained greenish-black rocks, which are probably all olivine-basalts.

Dykes of andesitic basalt containing corroded prisms of hornblende, which sometimes reach a length of  $1\frac{1}{2}$  inches, were noticed in the cliff 150 yards north-east of Port Maluag and on the shore a quarter of a mile north-west of Sron-an-Craoibhe. The Port Maluag dyke cuts a fine-grained olivine-basalt.

H. B. M.



*Ardmucknish Area.*—The Tertiary dykes of the promontory of Ardmucknish, on the west side of the Benderloch, present some interesting peculiarities which do not appear to be repeated among the numerous intrusions of the same age that occur in the south-west portion of the map. Two of these dykes have been described in detail by Mr. Bailey in a paper which was read to the Edinburgh Geological Society.\* Both are fine-grained rocks with a somewhat vitreous lustre, and under the microscope show variolitic structure in great perfection. Stellate groups of long narrow feldspars and plumose growths of augite lie in a small quantity of clear glassy base (Pl. VIII., fig. 1). These rocks are free from olivine, and contain numerous small vesicles filled with calcite. One of the variolitic dykes occurs near Ardentiny, at the north end of Ardmucknish; the other cuts a much larger dyke of decomposed dolerite in the north-east corner of Camas an Fhais. Both rocks are remarkably fresh, and Mr. Bailey concludes that there can be little doubt of their Tertiary age.

The other Tertiary dykes of this area which are represented in the Survey's collection are dolerites, camptonites, and monchiquites.

Several dykes of olivine dolerite accompany the variolite above mentioned as occurring at the north-east corner of Camas an Fhais. They are rather fine-grained and non-porphyrific; olivine is present only in minute granules. In most of them there are interstitial patches of brown glass. The augite has a purplish colour and forms little wedge-shaped areas between the long rectangular feldspars. Iron ores and apatite are present in some amount, but neither analcite nor biotite. Other rocks having these characters occur in different parts of Ardmucknish. They represent a normal type of Tertiary olivine dolerite, and differ in several respects from those containing biotite, hornblende and analcite, which occur along with them.

A dyke of well-preserved dolerite is found on the shore just south of Port a Bhuiltin. It contains many fresh olivines, highly idiomorphic, and often a millimetre in diameter, along with phenocrysts of augite in a ground-mass of augite, plagioclase, and magnetite. The pyroxene is usually zonal, and often shows hour-glass structure. Its colour is purplish-brown, but, especially towards its margins, a strongly-marked violet tint is noticeable, together with a feeble dichroism. The phenocrysts are idiomorphic and often composite (glomeroporphyrific); the smaller crystals of the second generation are less perfectly shaped, though not unfrequently exhibiting traces of crystalline form. The structure, however, does not approach the ophitic. The colour of the augites in the ground-mass resembles that of the outer zones of the phenocrysts. The feldspars are all small and lath-shaped; decomposition is more advanced in them than in

\* E. B. Bailey—"On the Occurrence of Two Spherulitic ("Variolitic") Dykes in Ardmucknish, Argyll," *Trans. Edin. Geol. Soc.*, vol. viii., p. 363, 1905.

any of the other minerals; they become cloudy with secondary mica and zeolitic minerals. Turbid, nearly isotropic areas appear around them; these may be a devitrified pale glassy base, but more probably are granular analcite. This mineral may be regarded as secondary, as it is usually mixed with calcite and other alteration products, and sometimes forms pseudomorphs after the feldspars. As the rest of the rock is very fresh, it is perhaps due to pneumatolytic changes immediately following consolidation. The magnetite which forms small octahedra in the ground-mass has often narrow rims of dark brown biotite. The appearance of interstitial analcite in this rock indicates affinities to certain varieties of teschenite. It has also close relationships to the camptonites and monchiquites of this area.

Several dykes of camptonitic character are known from Ardmucknish (Pl. VIII., fig. 2). One is found a half-mile south of Ardentiny; another occurs on the north-west corner of Camas an Fhais, and there are others in the peninsula. These are fine-grained rocks with small phenocrysts of augite and olivine. The latter mineral is usually decomposed; the porphyritic augite has pale brown and greenish-brown centres and darker violet margins, resembling the augite of the dolerite above described. The ground-mass of these rocks contains plagioclase, augite, and magnetite. The feldspar forms more or less perfect laths, and is partly labradorite, but has often zonal structure with extinction angles diminishing towards the outer borders. The pyroxene of the second generation also is remarkably idiomorphic, its short stout prisms yielding good cross sections. Magnetite in octahedra and apatite in very narrow needles abound in the ground-mass. Analcite appears also, partly with chlorite and calcite in small cavities, partly lying between the feldspars and other minerals like a ground-mass.

The affinities of these rocks with the camptonites are best shown by the abundance of dark brown, strongly pleochroic hornblende, and biotite of very similar colour and still more intense pleochroism. Both minerals occur principally in very good crystals, the biotite as thin plates with hexagonal cross sections, the hornblende in prisms with the typical six-sided transverse sections and elongated parallel to the principal axis. Biotite on the whole preponderates over hornblende. The amphibole often surrounds crystals of augite in parallel growth, being always later in crystallisation. The peculiar "ocellar" patches, consisting of subradiate feldspar and hornblende, so common in this group of rocks, occur in the dyke from Camas an Fhais. Their centres are occupied by analcite and calcite, and may originally have had a miarolitic cavity.

Another camptonite dyke occurs on the north-east corner of Sailean Sligenach. It is more coarsely crystalline and less distinctly porphyritic than the two others. Olivine has been present but not in great quantity, and is now weathered to calcite and serpentine. This rock contains abundance of dark brown horn-

blende and violet-brown augite in perfectly idiomorphic crystals. Parallel growths of these minerals are very frequent, the amphibole being peripheral. Plagioclase, iron oxides, and apatite form the rest of the rock, and calcite, chlorite, and analcite occupy spaces probably of miarolitic character. The abundant analcite suggests close affinities to the teschenites. The felspar includes labradorite and probably also andesine. Ocellar structure occurs also in this rock.

The analysis of the camptonite from Sailean Sligenach, Ardmucknish, is given below with several others for comparison.

|                                |     | I.      | II.    | III.   |
|--------------------------------|-----|---------|--------|--------|
| SiO <sub>2</sub>               | - - | 42.22   | 39.13  | 40.60  |
| TiO <sub>2</sub>               | - - | 2.49    | 4.02   | 4.20   |
| Al <sub>2</sub> O <sub>3</sub> | - - | 10.62   | 11.38  | 12.55  |
| Fe <sub>2</sub> O <sub>3</sub> | - - | 4.74    | 7.33   | 5.47   |
| Cr <sub>2</sub> O <sub>3</sub> | - - | .10     | ...    | ...    |
| V <sub>2</sub> O <sub>3</sub>  | - - | .05     | ...    | ...    |
| FeO                            | - - | 6.18    | 8.13   | 9.52   |
| MnO                            | - - | .50     | .42    | ...    |
| (CoNi)O                        | - - | .05     | ...    | ...    |
| CaO                            | - - | 14.80   | 11.77  | 10.80  |
| BaO                            | - - | .04     | ...    | ...    |
| SrO                            | - - | nt. fd. | ...    | ...    |
| MgO                            | - - | 8.68    | 8.64   | 8.96   |
| K <sub>2</sub> O               | - - | 1.41    | 1.93   | 1.19   |
| Na <sub>2</sub> O              | - - | 2.46    | 2.47   | 2.54   |
| Li <sub>2</sub> O              | - - | ? tr.   | ...    | ...    |
| H <sub>2</sub> O (at 105°)     | - - | .50     | 2.87   | 2.28   |
| H <sub>2</sub> O (above 105°)  | - - | 1.16    | ...    |        |
| P <sub>2</sub> O <sub>5</sub>  | - - | .73     | ...    | ...    |
| CO <sub>2</sub>                | - - | 3.57    | 2.41   | 2.68   |
| S                              | - - | .12     | ...    | ...    |
|                                |     | 100.42  | 100.50 | 100.79 |

I.—Sailean Sligenach, Argyllshire. (Anal., E. G. Radley.)

II.—Hoxa, Orkney. (Flett, *Trans. Roy. Soc. Edin.*, vol. xxxix., p. 387.)

III.—Gran. Norway. (Brögger, *Quart. Jour. Geol. Soc.*, vol. l., p. 15.)

More basic dykes than the above, containing principally augite and olivine, occur also in the peninsula. One of these is seen about 400 yards north of Fionn-aird and crosses also Garbh-aird, running in an east-south-east direction. It is about five feet broad, but splits up into three dykes where it reaches the west shore of Camas an Fhais. Through most of its course it is fine grained and much decomposed, but specimens taken from the dykes at the west side of Camas an Fhais are in a good state of preservation. The slides show small perfectly-fresh olivines, somewhat rounded by corrosion, and minute prisms of brownish augite, lying in a turbid. almost completely isotropic ground-



mass, which has the appearance of analcite. In this translucent, finely-granular matrix, minute subradiate fibres are seen with high powers; some of these have a weak birefringence, and may be weathered felspar. Iron oxides are abundant, and are mostly surrounded by narrow borders of dark brown biotite. A few minute prisms of brown hornblende may also be detected in the slide. In some parts the groundmass is a pale brown glass, which can be distinguished from analcite by its higher refractive index. Rounded patches of analcite occur in many specimens of this rock. They are clearly secondary, as they often contain idiomorphic crystals of calcite or dolomite. It is possible, however, that they are pseudomorphs after leucite, a mineral occasionally found in rocks of this group.

The special feature of this rock which is most interesting is the presence of large, rounded, corroded crystals of anorthoclase or soda microcline. These show no crystalline faces, and have a reddish-pink colour with two excellent cleavages. Under the microscope the microcline twinning is very prominent. In parts the sections of this mineral are entirely transparent, and show the microcline structure only very faintly; other parts have a turbid or granular character with less transparency, but in these the twinning is much more conspicuous and the double refraction stronger (Pl. VIII., fig. 3). With careful examination, however, the twin banding can be traced continuously from the turbid into the transparent parts of the mineral. The origin of these differences in optical character is not easily explained. They are known to occur also in the anorthoclase of the rhomben-porphyr which has been found on Kilimandjaro in Africa.\*

Small cavities in these felspars are filled with calcite and chlorite. Larger crystals of dark brown biotite are also included in the anorthoclase. They are much corroded and surrounded with dark borders full of finely granular magnetite. Their outlines also are rounded, though traces of the original perfectly idiomorphic outlines are very clearly discernible.

Monchiquite dykes with large anorthoclases are known to me only from one locality, the east of Fife, where they occur in some number around Elie. They have been described by Sir Archibald Geikie,† and the analysis prepared by Dr. Heddle‡ shows that the felspars belong to anorthoclase or a variety of orthoclase very rich in soda. Their optical properties are the same as those of the crystals from Camas and Fhais, and the rock in which they occur also is a monchiquite like that of Ardmucknish.

\* Finck, L.—“Die Rhombenporphyre des Kilimandsharo” *Festschrift, H. Rosenbusch*, p. 379 (1906).

† *Memoirs of the Geological Survey of Scotland*—“The Geology of East Fife,” by Sir Archibald Geikie, p. 240 (1902).

‡ Heddle—*Mineralogy of Scotland*, vol. ii., p. 2, anal. 8 (1901).

*Analyses of Monchiquite Dyke-rocks.*

|                                |     | I.      | II.    | III.   |
|--------------------------------|-----|---------|--------|--------|
| SiO <sub>2</sub>               | - - | 43.55   | 46.48  | 43.74  |
| TiO <sub>2</sub>               | - - | 2.52    | 0.99   | 2.80   |
| Al <sub>2</sub> O <sub>3</sub> | - - | 14.60   | 16.16  | 14.82  |
| Fe <sub>2</sub> O <sub>3</sub> | - - | 5.34    | 6.17   | 2.40   |
| FeO                            | - - | 7.46    | 6.09   | 7.52   |
| MnO                            | - - | .55     | ...    | ...    |
| Co(Ni)O                        | - - | .05     | ...    | ...    |
| BaO                            | - - | .27     | ...    | ...    |
| SrO                            | - - | nt. fd. | ...    | ...    |
| CaO                            | - - | 7.94    | 7.35   | 10.81  |
| MgO                            | - - | 4.77    | 4.02   | 6.98   |
| K <sub>2</sub> O               | - - | 1.40    | 3.08   | 2.90   |
| Na <sub>2</sub> O              | - - | 5.01    | 5.85   | 3.08   |
| Li <sub>2</sub> O              | - - | Tr.     | ...    | ...    |
| H <sub>2</sub> O (at 105°)     | -   | .63     | 4.27   | 2.94   |
| H <sub>2</sub> O (above 105°)  | -   | 4.58    |        |        |
| P <sub>2</sub> O <sub>5</sub>  | - - | .88     | ...    | 0.64   |
| FeS <sub>2</sub>               | - - | .31     | ...    | S 0.10 |
| CO <sub>2</sub>                | - - | .56     | 0.45   | 1.50   |
|                                |     | 100.42  | 100.91 | 100.23 |

I. West side of Camas an Fhais, Argyllshire. (Anal., E. G. Radley.)

II. Sta Cruz Bahn, Rio de Janeiro.

III. Rio do Ouro, Serra de Tingua, Rio de Janeiro.

A large anorthoclase phenocryst was broken out of this rock, pulverised, and washed with very dilute hydrochloric acid to free it from adherent calcite. It was then passed through a solution of borotungstate of cadmium. The specific gravity of the material selected for analysis was 2.608. The impurities present were a small amount of chlorite and iron oxide.

|                                |     | I.    | II.    | III.    |
|--------------------------------|-----|-------|--------|---------|
| SiO <sub>2</sub>               | - - | 65.83 | 1.0898 | 63.07   |
| Al <sub>2</sub> O <sub>3</sub> | - - | 19.97 | .1954  | 18.69   |
| Fe <sub>2</sub> O <sub>3</sub> | - - | .75   | .0047  | 2.47    |
| BaO                            | - - | .53   | .00345 | MnO .06 |
| SrO                            | - - | .29   | .0028  | ...     |
| CaO                            | - - | .22   | .0039  | 2.20    |
| MgO                            | - - | .05   | .0012  | ...     |
| K <sub>2</sub> O               | - - | 3.10  | .03287 | 6.62    |
| Na <sub>2</sub> O              | - - | 8.70  | .1401  | 5.50    |
| H <sub>2</sub> O (at 105°)     | -   | .07   | ...    | ...     |
| H <sub>2</sub> O (above 105°)  | -   | .18   | .0099  | 1.39    |
|                                |     | 99.69 | ...    | 100.00  |

I. Anorthoclase felspar in monchiquite dyke, west side of Camas an Fhais, Ardmucknish, Argyllshire. (Anal., Dr. W. Pollard.)

II. Molecular ratios of above.

III. Sanidine (anorthoclase), Kinkell, Fife (Heddle, *Mineralogy of Scotland*, ii., p. 2, 1901).

The analysis shows that the Ardmucknish felspar contains 18·38 per cent. of potash felspar, 73·80 per cent. of soda felspar, and 3·31 per cent. of lime (with barium and strontium) felspar. There is present also a small amount of kaolin (about  $1\frac{1}{2}$  per cent.).

The occurrence of dykes of olivine dolerite, camptonite, and monchiquite in this part of Argyllshire is of great interest. There can be little doubt that these rocks are of Tertiary age; they very closely resemble the similar dyke rocks of the Orkneys, which also are believed to be Tertiary.\* They show also that though no nepheline syenites of this period are known to occur in the West of Scotland, camptonites and monchiquites are fairly widespread, but not common. A similar assemblage is found also in the island of Scarba, about twenty-five miles to the south-west of Ardmucknish. The teschenitic character of some of those dykes (*e.g.*, Sailean Sligenach) recalls the Tertiary teschenites of Arran,† described by Mr. Harker, and the nepheline-bearing teschenite of Crawfordjohn‡ (which also is believed to belong to this epoch of intrusion).

The dyke of camptonite at Sailean Sligenach produces striking contact alteration in the rocks into which it is intruded. These are silky greyish or greenish-grey phyllites, consisting of chlorite and muscovite in very small scales arranged in parallel fashion among lenticular grains of quartz. The foliation is very pronounced, and is intersected by a slight crumpling. The rock contains also minute grains of zircon and iron oxide (Fig. 5, Pl. VIII.).

At the immediate contact with the dyke this phyllite is changed to a black vitreous substance (buchite, basalt-jaspis), which has much of the appearance of a pitchstone, but is minutely speckled with small white or grey spots. Under the microscope it is seen that the whole rock has been fused, and from the resulting glass, which is of a pale brown colour in thin section, crystals of cordierite, augite, magnetite, and spinel have separated. The magnetite is in exceedingly small and perfectly-formed octahedra, and is often grouped in clusters with transparent dark green crystals of similar shape and equally perfect. These latter have a very high refractive index, and must be assigned to spinel. The augite is in very long and narrow prisms, the ends of which are pointed, frayed, or forked. There is often a funnel-shaped glass cavity passing inward from the ends of the crystal, and when this is present at both terminations the crystal in longitudinal section has some resemblance to a capital letter H. Longitudinal and cross fractures are very common in these augite prisms. Their colour is dark green, and they have a distinct dichroism, best seen in the transverse sections. Referred to the direction of their elongation the sections are optically positive, and the scheme of pleochroism is Z—dark green, Y—paler green,

\* Flett, *loc. cit.*

† *Memoirs of the Geological Survey of Scotland*—"The Geology of North Arran," p. 112 (1903).

‡ A. Lacroix, "*Comptes Rendus*," cxxx., p. 1271 (1900).



X—brownish and pinkish-green. Extinction angles as high as 40 degrees were measured. Transverse sections have nearly square or rectangular outlines, and extinguish parallel to their sides; hence the prism faces are absent, and the bounding forms are the pinakoids. A few, however, show the typical octagonal outlines of pyroxene. Very often the corners of the crystals have grown outwards so rapidly as to form projecting spikes, while depressions correspond to the centres of the pinakoidal faces. The average diameter of these microliths is one or two hundredths of a millimetre; their length may be three-tenths of a millimetre.

The cordierite is the most conspicuous mineral in the slides. It is colourless and transparent except for crowds of enclosures of spinel, &c. I have not been able to detect any dichroism in this mineral, even after subjecting it to a red heat for some minutes. The crystals are rarely simple, but are mostly penetration twins on the plan usual in cordierite, and have the outlines of hexagonal prisms (Fig. 6, pl. VIII.) Cross sections in polarised light are resolved into a number of sectors (often three or six), which are beautifully clear when a selenite plate is inserted. Longitudinal sections are often characterised by a faint striping parallel to the long axes of the crystals, but all the bands have a straight extinction. A fairly good vertical cleavage can often be remarked in these pseudo-hexagonal prisms. They exhibit a strong tendency to aggregate in clusters which are often parallel, or at times sub-parallel growths. Their outlines are sometimes perfectly hexagonal, but very frequently the edges of the prisms show depressions which indicate the complex structure of the growths.

The other elements of this rock, on account of their small size, are mostly indeterminable. They include colourless prisms (perhaps felspar), which occur in felted masses among the clusters of cordierite; very minute globulites and microliths, which sometimes render the brown glass quite turbid; and small curved and branching transparent trichites (Fig. 5, pl. VIII.) There are also rounded spots, often with brown margins and composed of crypto-crystalline or spherulitic aggregates. These are, perhaps, steam cavities filled with siliceous infiltration products.

The specimens from contact with the dyke rarely show any grains of quartz, and these are invariably in a highly corroded condition, being merely residues of original grains with concavities on their surfaces where they are being attacked by the surrounding glass. The vitreous base is often flecked with spots and streaks of darker brown. Swarms of dark grains of magnetite and spinel sometimes render it nearly opaque; they often follow curved lines recalling the original foliation of the rock. The glass surrounding the partly-dissolved quartz grains is usually paler than elsewhere.

Specimens taken six inches from the edge of the dyke contain much clear glass with well-crystallised cordierites and dark swarms of magnetite and spinel, but contain a considerable

amount of undissolved quartz. At one foot from the dyke the quartz is almost as abundant as in the unaltered rock, but around it lies a turbid brownish substance, semi-opaque, and filled with innumerable small grains which seem to be magnetite and spinel; at any rate some are transparent, while others are black and opaque. There is no cordierite, and the chlorite and muscovite of the original rock are no longer traceable. At two feet from the contact, glass, spinel, magnetite, and probably augite micro-liths are visible, but there is a large amount of quartz partly corroded. In fact, this specimen is rather more altered than the previous one. Three feet from the contact the rock is a phyllite with muscovite, quartz, chlorite, and iron oxides, and shows little evidence of alteration under the microscope, but in the hand specimen has a darkened and indurated appearance. At five feet the same changes are visible, but in a less degree, and at six feet from the igneous rock the phyllite has quite its normal character.

Changes of a similar nature have been induced by basic sills in some of the Torridonian grits of the Isle of Soay. They have been described by Mr. Harker,\* who found that the sediments were vitrified and contained crystals of magnetite, cordierite, and a pyroxenic mineral. The cordierite formed small six-sided prisms, but did not show multiple penetration twinning. The same phenomena are widely known in connection with the Tertiary igneous rocks of the Continent,† and have been described also in shales which had been fused by contact with ignited seams of lignite.‡

In order to determine whether there had been any transfusion of material from the igneous dyke into the surrounding phyllites, which might be held to explain the ease and completeness with which fusion took place, chemical analyses were prepared by Dr. W. Pollard of the fused phyllite in contact with the camptonite and of the unmodified phyllite at a distance of six feet from the margin of the dyke. These are given below, and differ very little from one another. The vitrified phyllite is slightly richer in soda (0.76 per cent.), but is poorer in potash (1.42 per cent.). Hence there seems no reason to believe that there has been any transfer of alkalis. It is curious to note that the "buchite" is richer in combined water than the other, and this must be explained by supposing that the glassy base, so abundant in the former, contains a certain amount of water.

\* *Memoirs of the Geological Survey of Scotland*—"The Tertiary Igneous Rocks of Skye," by A. Harker, p. 245 and pl. xxi. (1904).

† A. Lacroix—"Les Enclaves des Roches Volcaniques" (1893). F. Zirkel—"Lehrbuch der Petrographie," B. III. (1894).

‡ E. L. Berstin—"Note on Baked Clays and Natural Slags in Eastern Wyoming," *Journal of Geology*, vol. xiii., p. 408 (1905).

|                                      | I.      | II.     |
|--------------------------------------|---------|---------|
| SiO <sub>2</sub> - - -               | 62.01   | 58.63   |
| TiO <sub>2</sub> - - -               | 1.02    | 1.01    |
| Al <sub>2</sub> O <sub>3</sub> - - - | 17.78   | 18.59   |
| Fe <sub>2</sub> O <sub>3</sub> - - - | 1.25    | 1.93    |
| FeO - - -                            | 6.63    | 6.46    |
| MnO - - -                            | .49     | .38     |
| (CoNi)O - - -                        | .04     | .03     |
| CaO - - -                            | .42     | .56     |
| BaO - - -                            | .05     | .06     |
| SrO - - -                            | tr.     | tr.     |
| MgO - - -                            | 2.04    | 2.62    |
| K <sub>2</sub> O - - -               | 3.43    | 2.01    |
| Na <sub>2</sub> O - - -              | 1.84    | 2.58    |
| Li <sub>2</sub> O - - -              | tr.     | ? tr.   |
| H <sub>2</sub> O (at 105°) -         | .08     | 1.38    |
| H <sub>2</sub> O (above 105°)        | 3.02    | 4.45    |
| P <sub>2</sub> O <sub>5</sub> - - -  | .11     | .08     |
| CO <sub>2</sub> - - -                | nt. fd. | nt. fd. |
| S. - - -                             | nt. fd. | nt. fd. |
|                                      | 100.21  | 100.77  |

I. Phyllite, Sailean Sligenach, Ardmucknish, Argyllshire, six feet from margin of camptonite dyke (unaltered).

II. Buchite or fused phyllite, with cordierite, etc., in contact with camptonite dyke, Sailean Sligenach, Ardmucknish, Argyllshire.

J. S. F.

b. *Acid Dykes*.—Although by far the larger proportion of the Tertiary dykes are of basic composition, a series of considerably more acid composition is found in the south-western corner of the map. This acid series occupies a zone or belt, of about a mile in breadth, stretching from the head of Loch Feochan in a general south-easterly direction to the southern margin of the map.

In many cases the more acid intrusions constitute simple dykes traversing the andesitic lavas of Lower Old Red age, but frequently they are seen to converge with basic dykes and unite to form compound or conjugate intrusions. Or these compound dykes may consist of an alternating series of basic and acid rocks, formed by the splitting up of the basic rocks by the more acid. These compound dykes may be well seen on the south-east side of Loch Feochan, and again in the area both to the north and south of the eastern end of Loch Scamadale. A well-marked line of these compound intrusions runs along the course of the Braglenmore Burn, south-east of the head of Loch Scamadale, and is continued to the north-west in the direction of the head of Loch Feochan.

The dykes of more acid composition than the dolerites and basalts consist of two types, the one being rather of a trachytic facies, the other being more acid and more nearly allied to the rhyolites. The trachytic type occasionally occurs as simple dykes, but is perhaps more usually found taking part in the

formation of the compound series. It forms a grey or greenish-grey rock of fine-grained texture, weathering with a rougher surface than the rhyolitic type, and breaking up into irregularly-shaped blocks, which sometimes show a rudely conchoidal fracture, while the basic dykes usually break up into more rectangular masses. These trachytic rocks are highly felspathic in composition, containing only a very small proportion of ferro-magnesian constituents, and some show affinities to the bostonites [10137]. Several examples of this trachytic type of dyke may be seen on the south side of the eastern end of Loch Scamadale, and again further south-east in the Eas nam Damh. Specimens from near the head of Eas nam Damh show under the microscope [10280, 10281] that the rock consists mainly of small lath-shaped plagioclase crystals, with ragged edges, and these often have a centric arrangement, and may thus give the appearance of imperfect spherulitic structures. There is a dark greenish interstitial substance, probably an alteration product after a ferro-magnesian mineral. There also appears to be some interstitial alkali-felspar present. Amygdules of calcite are not uncommon. Another specimen from the south side of Loch Scamadale shows [10282] much lath-shaped plagioclase with interstitial felspar and quartz, with chloritic patches, calcareous matter, and magnetite.

The more acid or rhyolitic types are also well developed in the Loch Scamadale area. They are usually various shades of grey in colour, and sometimes greenish and purplish, weathering to shades of grey, green, purplish, or yellowish. They are usually much shattered and decomposed, often too much so for satisfactory examination. They exhibit a well-marked flow-structure, and often break up on weathering, like a mass of slate, into thin plates parallel to the margin of the dyke. The course of these dykes is often sinuous and twisting, and branch-like offshoots are occasionally given off. They are usually compact and flinty at the margins and become holo-crystalline towards the more central portions. Phenocrysts of bi-pyramidal quartz crystals are occasionally seen in them, but the usual phenocrysts are small felspar crystals, or, on the other hand, porphyritic structures may be entirely absent.

A specimen of one of the acid dykes to the north of Loch Scamadale was examined under the microscope by Mr. Harker, and the following note, submitted by him, was published in the Summary of Progress of the Geological Survey for 1898:—"A dull, white, compact-looking rock with a few little glistening specks, which are crystals of quartz and felspar. The slice shows scattered porphyritic crystals, usually less than  $\frac{1}{50}$ -inch of quartz in good pyramidal crystals, and feldspars (albite and sanidine) sometimes intergrown in micropertthite fashion. The ground-mass is essentially of felspar and quartz, the latter evidently in great part of secondary origin. The felspar is in bunches of little prisms, but the original structure of the rock is much obscured. It seems to belong rather to the rhyolitic than



to the trachytic family. The secondary quartz of the ground-mass might be derived from the rock itself, or from an extraneous source, but the porphyritic quartz seems to mark the rock rather as one of acid composition, since the feldspars are doubtless all alkali-feldspars. Leaving out of account rocks of the dacite family (which is not in question here), porphyritic quartz crystals may be taken as characteristic of rhyolitic rocks of intrusive type; in the rhyolitic lavas they are often wanting."

Another dyke of the same class, seen on the shore near the head of Loch Feochan, shows under the microscope [10138] phenocrysts of quartz, orthoclase, plagioclase, biotite, and micropegmatite, in a very feldspathic ground-mass which is partly micro-poikilitic, and contains small grains of biotite and hornblende. Several of these dykes are well exposed in the Allt Braglenmore to the south-east of Loch Scamadale, and the following remarks are taken from Dr. Flett's notes on the microscopic sections [10139-10142]. They are fine-grained, greenish-grey vesicular, feldspathic rocks, with small phenocrysts of feldspar, which appears to belong to anorthoclase or varieties of plagioclase rich in alkalis. Some contain quartz as phenocrysts. In others the quartz appears to be secondary. The ground-mass is highly feldspathic, and mostly perfectly micro-poikilitic, and stained with small spots of limonite, chlorite, &c. These rocks are not ordinary quartz-porphyrries, trachytes, or bostonites. The abundance of an alkali-plagioclase, the feldspathic ground-mass with chlorite, the sparing amount of quartz, are suggestive of the quartz-keratophyres and keratophyres. The keratophyres, however, do not usually show a micro-poikilitic ground-mass. It is possible, however, that the rocks may belong to this class. Similar rocks occur in Eas nam Damh and show [10278] small phenocrysts of plagioclase and alkali-feldspar in a felsitic base, in part micro-poikilitic.

The occurrence of these rocks and also of the trachytic type in compound dykes, with the dolerites and basalts, has already been referred to above. These compound intrusions may consist of from two up to as many as seven distinct members. A good example of a compound dyke consisting of five members is seen in a small burn on the south side of Loch Scamadale. Thus at one margin we find an acid rhyolitic dyke with well-developed flow-structure; this is followed by a basalt, and the basalt by a trachytic dyke. This is succeeded by another basalt, which is again followed by a trachyte. If we follow up this intrusion we find that the rhyolitic dyke gradually diverges from the others and follows an independent course. Another compound dyke in Eas nam Damh consists of seven members, thus—basalt, rhyolite, basalt, trachyte, basalt, trachyte, basalt, in consecutive order from margin to margin. When traced, however, further to the south-east, we find the same compound intrusion consisting of only four members, thus—basalt, trachyte, basalt, rhyolite, the marginal basalts and one of the rhyolites having disappeared.

Several of the fissures occupied by these composite dykes can be shown to have been used as an escape for gases, after they had been filled by one or more of the earlier molten intrusions, as they are partly filled with agglomerate and tuff, made up of small fragments of these rocks as well as of the walls of the fissure, and through this agglomerate some of the more acid rhyolitic rocks can be seen to have risen. A very good example of such a dyke is exposed within a few yards of the road along the south shore of Loch Feochan, about one-third of a mile from its head. (Fig. 2.) The oldest rock filling the fissure is an olivine-basalt. (I., Fig. 2.) This is pierced by a massive dolerite dyke (II.), which

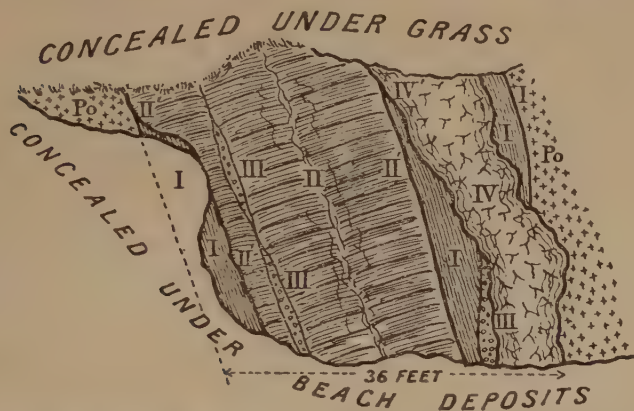


FIG. 2.—Composite Dyke exposed on south shore of Loch Feochan, near road, 4 miles south from Oban.

Po. Andesite lavas. I. Olivine basalt dyke. I'. Chilled edges of dyke. II. Dolerite dyke. II'. Chilled edges of dyke. III. Agglomerate filling cracks. IV. Rhyolite with bipyramidal quartz. IV'. Glassy margin showing fluxion structure.

exhibits chilled edges against the basalt. The dolerite and the basalt are traversed by fissures filled in with agglomerate (III.) formed by their fragments, and lastly a dyke of rhyolite (IV.) with bi-pyramidal quartz grains and showing fine fluxion structure along its margins cuts both the basalt and the agglomerate. The association of a similar type of agglomerate with these composite dykes is again a common feature in the Loch Scamadale area, and will be again referred to in connection with the vents.

c. *Vents*.—In connection with the Tertiary intrusions above described, a feature of special interest is the occurrence of masses of tuff, ash, and agglomerate, which apparently behave as volcanic vents. These vents are arranged along lines of fissure, occupied partly by simple and partly by composite dykes, which stretch from Balinoe, near the head of Loch Feochan, in a southeasterly direction past the head of Loch Scamadale, and thence extend along the course of the Allt Braglenmore to the southern

margin of the map. The vents are usually oval or elliptical in outline, or occasionally constitute elongated masses from 20 to 30 feet in breadth, associated with composite dykes. They are well seen in the small burn flowing down into Glen Feochan at Balinoe, and again there are excellent exposures in the bed of the Allt Braglenmore. Near the head of the former burn there is a good example of one of these vents, which was first noticed by Mr. R. G. Symes, and was described by him in the Annual Summary of the Geological Survey for 1898, page 154.

This vent is more or less pear-shaped in plan, narrow at the north end and widening southward, its maximum length being about 120 feet. It is filled with coarse agglomerate, some of the blocks of which measure two or three feet in diameter. The fragments consist largely of greenish and greyish rhyolitic rocks with well-developed flow-structure, but they also include pieces of the surrounding andesitic lavas of the pink biotite-porphyrite which occurs in the dykes and sills of the Lorne volcanic plateau, and of some basic rocks like the material of many of the Tertiary dykes. While the vent pierces the andesitic lavas and their associated porphyrite dykes, it appears also to truncate one of the numerous rhyolitic dykes of this district, already described. Thus, immediately to the south of it, appears a rhyolitic dyke which is exactly similar to the peculiar rock of which the blocks in the neck so largely consist.

A rather larger vent is very clearly exposed in the Allt Braglenmore, at its junction with the Allt Dearg, the burn which flows into it from Fineglen on its north-east side. This vent is roughly oval in outline, and is well seen for 50 yards or more up either burn above the junction. It pierces the andesitic lavas of Lower Old Red age. The included fragments, as in the case of the vent already described, consist mainly of rhyolitic rocks, basalt, and of the surrounding andesites. Some fragments also of epidiorite from the underlying schists were also observed in one of the neighbouring exposures of agglomerate. These fragments are cemented together in a finely fragmental matrix. The vent is seen in one place to have truncated and broken up one of the Tertiary dykes, while in another place it is cut by a rhyolitic intrusion.

Between this vent and the head of Loch Scamadale, and again occasionally in the Eas nam Damh to the east, smaller masses of a similar agglomerate have frequently been met with. Sometimes, as already observed, the agglomerate is seen to behave as elongated masses and to occupy the same fissure as one of the composite dykes. A good example of this is seen on the north-east bank of the burn, and the following section is exposed in crossing the ravine from south-west to north-east:—(1) A dyke of olivine-basalt from 2 to 3 feet in breadth; (2) lying against this dyke, agglomerate of about 3 feet in breadth, and consisting of fragments of basalt, rhyolite, and andesite; (3) an acid dyke of 4 or 5 feet in breadth; (4) agglomerate with a breadth of



about 20 feet, with angular fragments mainly of rhyolite; (5) resting against this agglomerate another acid dyke 18 to 25 feet broad. These five members occupy one and the same fissure, and each dyke appears to be distinct in itself and shows chilled edges against the agglomerate.

The proportion of rhyolitic to basaltic fragments in the different exposures of agglomerate observed frequently varies considerably, some masses being almost entirely made up of rhyolitic rocks, while others are mainly due to the breaking up of basalts. The material seen in the vents and fissures varies from a very coarse agglomerate to a moderately fine-grained fragmental rock resembling tuff.

It does not appear likely that these vents ever gave rise to any outpourings of lava; they rather mark the site of small local eruptions of an explosive nature, and their intimate association with a particular zone of dyke-formation further brings out their analogy to the small blow-holes and cinder-cones frequently observed in modern volcanic areas, as, for instance, in Iceland, formed by escaping high-pressure steam and gases along lines of fissure. They belong essentially to the period of the formation of the outlying dykes of Tertiary volcanic times, connected with some larger focus such as that of Mull. Though later than the formation of some of these rhyolitic and basaltic dykes, the material of the vents was itself again pierced by others of these dykes, so it is probable that the eruptions which they indicate had ceased before the final dying out of the dyke-forming phase.

H. K.

*Oban and Kilmore Area.*—Two distinct vents occur along the course of the composite dyke north of that first described by Mr. Symes.\* The nearest to the latter is about a quarter of a mile to the N.N.W., and floors the bottom of the deep gorge which opens on the Feochan valley at Ballinoe for about half a mile from its head, having an average breadth of only about 200 feet, and is, therefore, a typical fissure-vent. It has followed the same fissure which has been taken advantage of by the earlier basic dykes, but the explosion has disrupted the dykes and a good portion of the andesites and their older porphyrite intrusions, the broken ends of several of which are seen on each side of the vent. The neck is chiefly filled by a comparatively fine-grained agglomerate or tuff composed of fragments of the rocks through which the vent has been driven, but with the addition of rhyolitic and felsitic material; the whole being much decomposed. In this neck there is evidence that the explosive conditions were followed by flows of rhyolite, which are seen cutting the agglomerate, and isolated masses of agglomerate are found included within platy rhyolite in such a manner as to show that they were rolled along and wrapped up within the highly viscid lava in its passage up the vent.

\* *Summary of Progress for 1898*, p. 153-154.



A second vent also occurs in the gorge near its foot just above Ballinoe. It is almost circular, with a diameter of about 300 yards, and pierces the andesitic lavas and the basic dykes. It is partly filled with coarse agglomerate on its west side, which contains a large proportion of felsitic debris. Through this has welled up a felsitic rock with platy fluxion structure, the planes being much involved. The rock gives off apophyses, and appears to be merely an expansion of the rhyolitic dykes which connect this vent with the one to the south, and which can be seen splitting up the basic dykes both to the north and south of the vent.

B. N. P.

## CHAPTER X.

### CONTACT METAMORPHISM PRODUCED BY THE NEWER IGNEOUS MASSES.

The huge granitic mass of Ben Cruachan affords special facilities for the study of the phenomena of contact metamorphism, for not only does it comprise an enormous body of eruptive material, but the sedimentary formations around it had undergone comparatively so little alteration before it invaded them, that its effects upon them can be satisfactorily studied over a large area. It is not possible, however, to define a definite aureole of metamorphism round the granite, on account of the exceedingly variable nature of the rocks affected by it. Thus, along the greater portion of the granite margin comprised within the present map, the older sediments consist of alternations of different material which have been affected in different degrees. Hence, in some areas, such as that of the Pass of Brander, where we have mixtures of quartzose and argillaceous materials and impure calcareous beds, we have a high degree of contact alteration; while in other areas, such as that bordering part of the eastern margin of the granite, where highly quartzose and granulitic rocks occur which underwent considerable metamorphism previous to the granite intrusion, the later metamorphism of the contact type is only comparatively slight. Nor is it always possible, along the southern margin of the granite, to trace the highly contact-altered rocks into their least-altered representatives, owing to various causes, such as the folding of the rocks, and the overlapping of rocks of a different type such as the volcanic series of Lorne. Moreover, the extent to which the country around Ben Cruachan is cut up by lochs and rivers prevents to a great extent the possibility of tracing any particular rock from its least-altered state up to its contact with the granite. However, in spite of these obstacles, it has been found that a well-marked zone of contact alteration can be followed along the margin of the granite from the head of Loch Awe along the Pass of Brander to Bonawe, and to the west of Loch Etive this alteration zone may be traced continuously along the entire western margin of the granite. We thus have a belt of contact-altered rocks extending continuously for a distance of about 17 miles. The maximum breadth of this belt is about a mile and a half on the western side of the granite and about a mile in the Pass of Brander area.

We will deal first of all with the district near the head of Loch Awe and the Pass of Brander.

## 1. LOCH AWE DISTRICT AND THE PASS OF BRANDER.

In this area the members of the schistose rocks, on being traced up to their contact with the granite, are found to have undergone very considerable contact-alteration. The degree of alteration increases towards the granite in such a manner as to leave no doubt that it has been caused by the direct action of the granitic intrusion. The sedimentary rocks here exposed may be conveniently divided into the following groups:—

- (1) A banded calcareous series of the Pass of Brander. These rocks are especially well seen in the neighbourhood of the Falls of Cruachan, and occasionally good bands of pure limestone are intercalated among them.
- (2) The black schists of the south and south-eastern slopes of Beinn-a-Bhuiridh.
- (3) Quartzose schists, frequently containing some proportion of argillaceous material, and quartzites of the eastern portion of Beinn-a-Bhuiridh and Monadh Driseag.

Calcareous beds occasionally occur with the black schists, and black schists are frequently intercalated with the more quartzose beds.

During the mapping of this area a large number of specimens were collected at various distances from the granite, and these were submitted for microscopic examination to Dr. Teall. The following account of the contact-alteration of these rocks is mainly taken from Dr. Teall's report on the microscopic sections and specimens.

(1) *The Banded Calcareous Series.*—"The rocks of the banded calcareous series were evidently fine-grained sedimentary rocks, in which the relative proportions of argillaceous, arenaceous, and calcareous material were liable to repeated variations. Subsequent to their formation they must have been folded and cleaved, so that the original laminæ of arenaceous and calcareous material were more or less broken up into lenticular folia. Sometimes the different types of sediment were, as it were, kneaded together without the development of any well-defined parallel structure. This, however, only applies to small portions of the specimens. Strain-slip cleavage is often recognisable in the dark bands. The contact action appears to have been subsequent to the movement, and to have destroyed to a great extent the schistosity produced by it.

"The rocks are now fine-grained or compact, and consist of thin alternating folia of a dark purplish and pale grey, greenish, or yellowish colour. The dark folia represent the more argillaceous laminæ of the original sediment. They are now largely composed of a confused aggregate of micaceous and chloritic minerals, amongst which the characteristic brown mica may be observed. In one or two specimens small albites occur, as they do in some of the albite-schists; but it may be doubted whether this mineral is due to contact-action.

“The light-coloured folia represent in most cases the more calcareous laminæ of the original sediments. They are rich in minerals of the type usually occurring in impure limestones which have been subjected to contact action. A colourless or pale green pyroxene and a colourless garnet are the two most characteristic minerals, but epidote and hornblende also occur. The pyroxene is usually present in small grains, and only occasionally attains dimensions large enough to show characteristic cleavages and optic properties. Under these circumstances, it is not always easy, in the absence of colour, to distinguish the pyroxene from a mineral of the epidote-zoisite group.

“Where carbonates have been preserved, which, however, is rarely the case, a narrow zone of granular pyroxene may be frequently seen separating them from quartz. The garnet is colourless, and often shows the anomalous double-refraction of grossularite. Like the pyroxene, it forms narrow zones round a carbonate, with respect to which it is idiomorphic.

“In some rocks [*e.g.*, 8238] epidote takes the place of pyroxene, and the pale yellow folia are then formed of epidosite—a rock composed of epidote and quartz. One or two specimens contain large crystals of apatite, which appear to have been developed *in situ*, for they are too large to be regarded as original clastic constituents. Sphene is sometimes an important accessory, and is often deeply coloured and idiomorphic. The other minerals, of which quartz and hornblende are the most important, do not call for special notice.

“One specimen belonging to this group [8251] is of exceptional interest.\* It is a rock of compound origin, consisting of igneous and sedimentary material most intimately interblended. Thin folia, largely composed of granitic material, may be seen traversing the banded hornfels of the normal type, parallel to the banding. But there is no sharp line of demarcation between the two, although the granitic folia are coarser in grain than those which consist of sedimentary material. Under the microscope the interblending of the two kinds of material is very obvious. To the granite must be referred orthoclase, oligoclase, biotite in large plates, and some of the quartz; to the sedimentary rock, biotite in minute scales and aggregates, granular pyroxene, and the remainder of the quartz. The sphene and hornblende probably also belong mainly to the sedimentary rock. It is especially worthy of note that, although the granitic folia are only two or three millimetres in breadth, the individuals are as large as those occurring in ordinary granite (1 or 2 mms.). This clearly shows that the whole rock must have been subjected to the physical conditions under which the granite consolidated. The granitic invasion has clearly followed by preference the calcareous folia, for the granular pyroxene occurs abundantly as inclusions in all the granitic minerals except the biotite, whereas the dark purplish

\* This specimen was obtained at the granite contact from the ridge due east of the Cruachan burn.



bands of biotite-hornfels retain their normal character, and do not show the same tendency to blend with the granitic constituents.

"That a granitic magma should possess the power of eating up limestone we can well understand, but it is doubtful whether that power can be appealed to in the present case as an explanation of the facts above referred to, for the granitic magma does not appear to have changed its composition. It is now represented by the same minerals as those of normal granite, and the pyroxene of the calc-silicate-hornfels merely occurs as inclusions in these granitic minerals. There is, therefore, direct evidence that the lime has never been incorporated in the magma. Seeing, however, that the granite of the district is associated with quartz-diorites and basic diorites, it becomes important to ascertain whether these rocks may be due to the absorption of sedimentary rocks.

"In any case, we are here dealing with a rock of compound origin. It is neither an igneous rock nor a sedimentary rock, but a mixture of the two.

"Attention was directed to the existence of such rocks many years ago by M. Michel Levy,\* who recognised two types. In the one the granitic material has been, so to speak, superposed upon the sedimentary rock, so that the contact materials float in a granitic matrix (superposition). In the other type the injection has taken place between the folia (injection "lit par lit"). Both these types are represented in this specimen. The granitic material has penetrated the sedimentary rock between the thin bands of biotite-hornfels, and has, moreover, superposed itself to some extent upon the bands of calc-silicate-hornfels, so that the contact-pyroxene occurs as inclusions in the orthoclase, oligoclase, and quartz of the granite."

Professor Lacroix, in his observations on the granite of the Pyrenees, has also described cases in association with contact phenomena very similar to that now under consideration.† He describes passages between schists impregnated with granite, and granite impregnated with schist, and says that feldspathisation of the schists has been caused (*a*) by imbibition, (*b*) by injection—*i.e.*, by granitic material injected between the laminæ (injection "lit par lit").

In the banded calcareous series of the Pass of Brander bands are frequently met with, sometimes a few feet in thickness, of more or less pure limestone. This material is found to be converted into a finely crystalline, nearly white or greyish marble (Cipolin). A specimen, one-sixth of a mile from the granite, from the ridge east of Cruachan Burn, is a crystalline granular aggregate of calcite, with some irregular grains of diopside, and a few flakes of mica.

\* Sur les Schistes Micacés des Environs de Saint-Léon (Allier). *Bull. Soc. Geol. France*, 1881, pp. 181-196.

† Lacroix. "Le Granite des Pyrénées et ses phénomènes de contact."—*Bull. des Services de la Carte géologique de la France*, No. 64, p. 8, 1898.

(2) The *Black Schists* are found near the granite to be altered into dark compact hornfels, in which quartzose lenticles are often present. Where arenaceous material has been interlaminated with argillaceous, a more or less compact hornfels has resulted with strongly-marked dark and pale, or sometimes reddish bands. A specimen of the altered black schist from the south side of Bena-Bhuiridh is a dark compact hornfels with quartzose lenticles. Dr. Teall reports that under the microscope "the dark hornfels is seen to be thickly crowded with black opaque particles and patches. The substratum in which these particles lie is crystalline, but the minerals are not easy to identify. Amongst them are two colourless minerals which differ markedly in their refractive indices, and one of which may be felspar. The quartzose lenticles are aggregates of quartz with films and patches of a pale coloured biotite often occurring in small scales. The distribution of these films shows that the rock was puckered, and in some cases the films may be traced as inclusions through comparatively large individuals of quartz, thus proving that to some extent at least the crystallization was subsequent to the movement."

A dark, compact, banded hornfels, from the south side of the Pass of Brander, shows strain-slip cleavage, and was doubtless originally composed of alternating gritty and argillaceous layers. The former are now composed of quartz grains and minute scales of chloritic and micaceous minerals. The argillaceous layers are mainly composed of chloritic and micaceous minerals, amongst which brown mica may be recognised. The effect of the contact action has been to destroy to a great extent the previous schistosity of the rocks. Some reddish bands which occur in the hornfels of this type consist of a granulitic aggregate of quartz and turbid felspar, while epidote, zircon, and sphene occur as accessories. These bands probably represent laminæ of a fine-grained felspathic sandstone.

(3) The *Cordierite-bearing Rocks* which occur among the altered sediments (quartzose schists, biotite-hornfels, &c.) of the eastern and northern portions of Monadh Driseag, at the back of Loch Awe Hotel, have been carefully studied by Dr. Teall, who furnishes the following report regarding them\* :—

"Another very interesting type of metamorphic rock is characterised by the presence of cordierite. This type is represented by medium-grained, often bluish-grey, fairly massive rocks, of which a specimen from the north-east side of Monadh Driseag [8254] may be selected as a type. Under the microscope one sees an aggregate of colourless minerals, in which lie detached scales and nests of biotite, and patches crowded with small grains and imperfect crystals of a green spinelle. The colourless minerals are cordierite, alkali-felspar, and oligoclase. The individuals vary in size, often measuring one or two mms. across, but rarely show any trace of crystalline form. The cordierite contains biotite,

\* *Summ. Prog. Geolog. Survey for 1898*, pp. 86-91.

often in minute rounded scales, spinelle, and zircon, as inclusions. It is difficult in an ordinary slide to distinguish in all cases the felspar from the cordierite, as both have approximately the same refractive and double-refractive power. The characteristic yellow pleochroic halos surrounding the zircons in the cordierite are then the most useful means of distinguishing between the two minerals. But if a thin slice be heated on platinum foil, a change is produced in the cordierite. The pleochroic halos disappear, and a faint yellow colour seen best in one position of the polariser is developed all over the mineral. This faint general pleochroism, produced by heating, is not so marked as that of the halos, but is sufficient to distinguish the cordierite from the felspar, which remains absolutely colourless. In this way it can be shown that half, or possibly even more than half of the entire rock is composed of cordierite. Of the felspars, orthoclase is the most abundant. Pyrite occurs in grains, and as irregular masses wedged in between the other constituents. Quartz has not been observed in the specimen selected as a type.

"The occurrence in a slide [8254] of this rock of one or two colourless grains with very high refractive and moderate double-refractive power, led to a search for *corundum*, which proved successful. The coarsely-powdered rock was treated for about forty-eight hours with hydrofluoric acid, and the residue boiled with nitric acid to remove the pyrite. As the microscope disclosed the presence of some corroded fragments of andalusite, the powder was placed in methylene-iodide of sp. gr. 3.315. The final residue was then found to consist of corundum, green spinelle, and one or two crystals of rutile. The corundum occurs in irregular grains and crystals up to .3 mm. in diameter. The crystals show a tendency to a tabular form, with hexagonal outlines. Those which are lying flat on the slide, and which show this outline, appear dark under crossed nicols, and give as a rule a negative uniaxial figure. Parallel striations in three directions at right angles to the sides of the hexagon may frequently be observed. These are in most, if not in all cases, due to repeated alternations of the rhombohedral and basal planes, in which the latter usually predominate. In this way a stair-like termination to the hexagonal prism is often produced."

"The forms observed are those of a hexagonal prism [1120], a rhombohedron [1011], and the basal pinacoid [0001]—a characteristic combination for corundum, and one commonly seen in the Burma rubies and Montana sapphires. The steep pyramidal planes, so characteristic of the Ceylon and Kashmir sapphires and the common corundums of Madras, have not been observed. Inclusions of green spinelle and cavities, usually irregular, but sometimes in the form of negative crystals, are not infrequent.

"Other specimens of the cordierite-hornfels differ from the type in the relative proportions of the different constituents, in the presence of quartz, sometimes considerably abundant, and to a certain extent also in structure. One specimen [7618] is especially



interesting as furnishing conclusive evidence as to the relative age of the crystallisation of the cordierite and the movements which have so powerfully affected the sedimentary rocks of the district. Apart from a few large patches of pyrite and flakes of biotite ( $\cdot 4$  mm.), this rock is composed of extremely minute opaque grains and plates (ilmenite  $\cdot 01$ – $\cdot 02$  mm.) scattered through a granulitic aggregate of cordierite, quartz, andalusite, and felspar. Sometimes the grains of cordierite attain a considerable size, and then the section loses its granulitic character. Sericitic mica, zircon, and rutile occur as accessory constituents.

“The distribution of the minute opaque particles clearly shows that the rock was puckered with the occasional development of strain-slip cleavage, but this puckering has had no effect whatever on the cordierite, or on the other colourless constituents. All these in their present form have been clearly developed since the movement took place.

“This rock is interesting from another point of view. Puckering of the type here revealed is only known in phyllites and slates—that is, in rocks which were originally fine-grained sediments rich in argillaceous material. Out of such sediments the cordierite-bearing rocks have doubtless been formed, the alkali of the micaceous minerals going to form felspar, while some, or all, of the magnesia present combined with alumina and silica to form cordierite. The poverty of this rock in micaceous minerals, so common in the phyllites, is thus explained, and the simultaneous formation of cordierite and alkali-felspar is accounted for.

“In the Explanation of Sheet 75 of the Geological Survey of Scotland (1896) a general account of the characters and distribution of the cordierite-bearing rocks of Scotland, so far as these were known at the time, was given. Since that date Mr. Barrow has sent up another series from Sheet 65 (Aberdeen and Forfar).<sup>\*</sup> They present many points of resemblance to the rocks above described. There is the same association of cordierite, andalusite, biotite, and a green spinelle, with a variable amount of quartz and felspar; but the rocks are coarser in grain and always contain sillimanite, sometimes also garnet. One of these rocks [7085], containing cordierite, sillimanite, andalusite, felspar, biotite, ilmenite, and the green spinelle, was analysed, and the analysis is quoted as throwing light on the composition of the original sediment. It agrees remarkably with the analysis of a cordierite contact-rock from Monte Avicco, described by Salomon, which is quoted for comparison.

<sup>\*</sup> See also Dr. Flett in Memoir on The Geology of Lower Strathspey (Explanation of Sheet 85), p. 55, and in the Memoir on the Land's End District (Explanation of Sheets 351 and 358).



|                                |       | I.            |     | II.           |
|--------------------------------|-------|---------------|-----|---------------|
| SiO <sub>2</sub>               | - - - | 42·08         | -   | 44·62         |
| TiO <sub>2</sub>               | - - - | 2·16          | -   | 2·04          |
| Al <sub>2</sub> O <sub>3</sub> | - - - | 32·40         | -   | 33·33         |
| Fe <sub>2</sub> O <sub>3</sub> | - - - | 13·44         | { - | 7·32          |
| FeO                            | - - - |               |     | 5·45          |
| MgO                            | - - - | 3·30          | -   | 5·46          |
| CaO                            | - - - | 1·42          | -   | 0·12          |
| K <sub>2</sub> O               | - - - | 2·20          | -   | 0·68          |
| Na <sub>2</sub> O              | - - - | 1·60          | -   | 0·53          |
| Ignition                       | - - - | 1·60          | -   | 1·47          |
|                                |       | <u>100·20</u> |     | <u>101·02</u> |

I. Cordierite-gneiss, from the north end of Black Hill, Aberdeenshire. [Teall.]

II. Cordierite-contactfels, Monte Aviole. "Geologische und Petrographische Studien am Monte Aviole," von W. Salomon. *Zeit. Deutsch. Geol. Gesell.*, 1890, p. 502.

"The principal difference between the two analyses lies in the greater amount of alkali in the Scottish rock. But Salomon states that his specimen was specially selected on account of its containing very little felspar, and less biotite than the average rocks of the group; so that, if an average rock had been selected, the agreement might still have been closer.

"The close correspondence between the cordierite-bearing rocks of the Ben Cruachan area and those of Monte Aviole is especially interesting, because in both cases the granitic rock is of the same type. It is a tonalite or quartz-mica-diorite, rather than a true granite.

"There is another point of some interest which deserves mention in this connection. In the Explanation to Sheet 75 (Scotland) special attention was directed to a rock of compound origin belonging to this group [3693]. 'The igneous portion is represented by more or less idiomorphic oligoclase, biotite, micro-poikilitic orthoclase, and quartz; the metamorphic portion by cordierite, quartz, biotite, sillimanite, and a green spinelle. The rock into which the granitic magma was intruded is now represented by somewhat ill-defined shreds, patches, and streaks, in a paste of igneous origin' (*l.c.*, p. 37). It is not possible to distinguish igneous from sedimentary material in the Ben Cruachan specimens, nevertheless something of the same kind as that above referred to may have taken place, especially as there is direct evidence that this has been the case with the bands of pyroxene-hornfels in the 'banded series.' We thus see that the cordierite-bearing contact-rocks, which always belong to the inner zones of contact metamorphism, and often occur at the actual junction, are peculiarly liable to be invaded by igneous material and more or less broken up. Salomon describes inclusions of the cordierite rocks in the tonalite of Monte Aviole, and concludes from the occurrence of garnets and large crystals of biotite in a zone surrounding these inclusions, that the composition of the tonalite-magma was modified by the absorption of some of the contact material.

“Under these circumstances it is particularly interesting to note that cordierite, in association with the same minerals—sillimanite, green spinelle, orthoclase, plagioclase, etc.—occurs frequently in the ejected blocks of the Laacher See,\* and as inclusions in the andesites and less frequently in the trachytes of the Eifel and Siebengebirge.† Mineral aggregates of cordierite, andalusite, sillimanite, felspar, biotite, pleonaste, corundum, rutile, quartz, garnet, zircon, and magnetite, bearing the closest resemblance to the contact-rocks of Monte Aviole and Ben Cruachan, occur as fragments and ‘schlieren’ in the hornblende-andesite of Bocksberg and Reugensfeld in the Eifel (Vogelsang). The fragments are usually rounded, but sometimes angular. They may attain a diameter of 6cms., while the ‘schlieren’ may be 16cms. in length. The larger fragments are often easily separable from the matrix, but the ‘schlieren’ may be most intimately blended with it. These inclusions vary in size, and are often so small as to be only recognisable under the microscope. It seems impossible to avoid the conclusion that we see in the process which goes on at the contact of plutonic rocks, the agency by which inclusions of the kind described by Vogelsang are introduced into igneous magmas, and it is certainly remarkable, though possibly only an accidental coincidence, that the hornblende-andesites of the Eifel should be the volcanic representatives of a tonalite magma similar to that which formed the masses of Monte Aviole and Ben Cruachan.

“This is not the place to enter upon a general discussion of the natural history of the cordierite-bearing rocks, but one or two remarks may perhaps be admitted. The mineral occurs in many igneous rocks such as granite, quartz-felsite (Cornwall), liparite, kersantite; and although in some of these it is clearly not the result of crystallisation from the normal igneous magma, in others it possesses all the characters of a mineral so formed. This, for example, is the case of the cordierite of the kersantite of Michaelstein in the Hartz, where it occurs in idiomorphic crystals. Nevertheless, a doubt is suggested as to whether, even in this case, it can be regarded as a mineral belonging to the igneous magma, for the rock in which it occurs contains numerous inclusions, made up of sillimanite, andalusite, kyanite, spinelle, and other minerals usually associated with cordierite in contact rocks and crystalline schists. Moreover, the mineral itself contains spinelle as inclusions. It seems probable, therefore, that in some way or other the presence of cordierite in the kersantite of Michaelstein is due to the influence of the contact rocks upon the igneous magma, in which case it must be regarded as an endomorphic contact mineral.

“Apart from the somewhat rare and sporadic occurrence of cordierite in ejected blocks and igneous rocks, we find the mineral

\* “Mikroskopische Untersuchung der aus krystallinischen Gesteinen herrührenden Auswürflinge des Laacher Sees”; von Carl Dittmar. *Verh. d. Naturh. Vereines.* Bonn. 1887, p. 499.

† Beiträge zur Kenntniss der Trachyt und Basaltgesteine des hohen Eifel. Carl Vogelsang. *Zeit. deutsch. geol. Gesell.* 1890, p. 1.

in crystalline schists of doubtful origin, and in contact-rocks. Its mode of origin in the latter case is fairly clear. It has been produced by the metamorphosis of sedimentary rocks, containing argillaceous material. The presence of 2 or 3 per cent. of magnesia is common in slates and shales, and as 3 per cent. of magnesia is sufficient to make about 30 per cent. of cordierite, when combined with silica, alumina, and iron, it is clear that rocks of this type furnish the necessary chemical conditions. Do these facts throw light on the origin of the crystalline schists containing cordierite—on the origin of the cordierite-gneisses? It is probable that they do, especially when taken in connection with the evidence of the tendency of the igneous magmas to invade, and even impregnate, the rocks of the inner contact-zone. Suppose the phenomena of metamorphism, injection, and impregnation, which must have taken place round the Cruachan mass, to be intensified and accompanied by plastic deformation—have we not then a rational explanation of the origin of many of the complex groups of crystalline schists which cannot be definitely classed as the metamorphosed representatives of either igneous or sedimentary rocks?"

## 2. AREA ABOUT BONAWE.

Passing now to the area on both sides of Loch Etive, in the neighbourhood of Bonawe, we find that along the western slopes of Ben Duirinnis the altered rocks seem to belong mostly to a series of medium and fine-grained felspathic grits alternating with dark slates, which often contain quartzose bands. Close to the granite these strata have been altered into compact and medium-grained hornfels of a dark grey colour, biotite-hornfels (representing the more slaty portions), and occasionally a finely-banded hornfels. A grey fine-grained hornfels, 10 yards from the granite, shows under the microscope [7617], alkali-felspar, quartz, biotite, sericitic-mica, pyrites, very pale green hornblende (?), and rutile. The felspar usually forms a mosaic, or occurs as grains in large patches of micro-poikilitic quartz. More rarely it occurs as large regular grains with inclusions of quartz. There is no trace of the original elastic structure—all the constituents are authigenic and authimorphic. Several other specimens, however, in addition to the above constituents, appear undoubtedly to contain cordierite in the form of shimmer-aggregates [7618, 7619, 7620, and 7623]. The occurrence of cordierite-hornfels as a contact rock connected with the Ben Cruachan mass is very interesting. The specimens containing cordierite were taken mostly from exposures a few inches from the granite, or from small included patches of altered rock within the granite mass.

In the banded hornfels some layers consist of biotite and a micro-crystalline mosaic; others contain small grains of malacolite or epidote, and iron-ores. Possibly the original rock was a slate interlaminated with impure calcareous bands—a common feature in the black slate series of Loch Awe side.



Patches of altered sedimentary rocks are exceedingly numerous on Ben Duirinnis as inclusions within the granite. In some places, indeed, the granite and sedimentary rocks are inextricably intermingled; the latter may be abundantly veined by the former, or the granite may be crowded with inclusions of the sedimentary material of all sizes. These inclusions closely resemble the altered rocks along the granite margin, and the larger masses maintain as a rule the normal strike of the folds, as shown by the beds outside the granite mass. The material of these inclusions does not appear to have been incorporated into or assimilated by the granite. The outlines of even very small fragments remain perfectly sharp, and the granite immediately surrounding them does not exhibit the least departure from its normal facies. The intrusion of the granite would appear in this area to have behaved like a gigantic complex sill, running in along lines of weakness in the folds, and injecting itself along the cleavage-planes of the slates and grits, frequently detaching and enveloping portions of them in its course, and thus forming a marginal area (rather than a boundary-line) of exceeding complexity.

About a mile to the north-east of Bonawe several included patches of altered sedimentary rock occur, which probably represent the impure limestone so common throughout the series about Loch Awe side. They consist for the most part of a highly contorted greenish and dark grey rock, the grey and green portions being closely interlaminated. Sometimes the banding is parallel, but more frequently much crumpled. These bands doubtless represent two fairly distinct varieties of rock, the green portion being the product of an impure limestone, while the grey part represents shaly or slaty bands. Occasionally, distinct banding is lost, and the rock consists of an intimate intermixture of the two varieties. Even under the microscope the lamination is often clearly seen. The greenish variety is composed of ragged micro-poikilitic plates of biotite, granular malacolite, hornblende (scarce), and quartz in large micro-poikilitic patches, and forming, as it were, in places the substratum of the entire rock. Felspar is also sometimes present. The green colour of the rock is certainly due to the pyroxene. No carbonates are present. The malacolite is the most important constituent, and the rock may therefore be termed malacolite-hornfels. The micro-poikilitic structure is very perfectly seen in the biotite and quartz.

The darker variety of the rock contains little or no malacolite. It is composed of micro-poikilitic pale green hornblende, biotite, and a colourless mosaic (quartz and felspar). In some slides [7614] nests of a colourless granular sphene occur. Thus, a banded rock formed of calc-silicate is interlaminated with biotite-hornfels. It is unfortunate that the occurrence of this rock as isolated patches prevents it from being traced into its unaltered representative.

From the Bonawe area the hornfels zone may be followed, as already remarked, along the entire western margin of the granite



to the northern edge of the map. The rocks which have here been altered by the granite are essentially the same as those occurring in the Pass of Brander and about the head of Loch Awe, and show similar petrological characters, and the detailed description which has already been given of these rocks will apply here equally well.

As is well known, the older sedimentary rocks of the Loch Awe and Pass of Brander districts are intersected by numerous sills of hornblendic and chloritic schists, epidiorite, &c. It is difficult, however, to work out the exact nature and extent of the alteration which the granite has produced upon these rocks, on account of their varying character, and the differences which occur even in one and the same sill. Specimens from one of the small sills on the south side of Beinn-a-Bhuiridh, near the head of Loch Awe, were examined under the microscope. About a mile from the contact with the granite, the rock is a normal foliated epidiorite, with epidote and chlorite, and shows no signs of contact-action. At a third of a mile from the granite, brown mica of the contact type is very characteristic, and the rock is extremely hard and compact, but in other respects it does not differ markedly from many of the epidiorites of the same neighbourhood. It was not, however, found possible to procure actual contact specimens of any of these smaller sills. A similar alteration of the small dyke-like intrusions of epidiorite was observed near the granite margin to the east of the head of Loch Creran.

There is thus conclusive evidence of very decided contact-action, wherever the ground immediately surrounding the Ben Cruachan type of granite has been examined. In the Pass of Brander and the area bounding the eastern spurs of Ben Cruachan, this action is shown by Dr. Teall's detailed researches to have been exceedingly intense. The sedimentary rocks may be followed from their comparatively unaltered condition, as seen in the neighbourhood of Kilchrenan and other parts of Loch Awe side, into the different varieties of hornfels, some containing cordierite, of the Pass of Brander and the slopes of Beinn-a-Bhuiridh. The hornfels-alteration of similar rocks, with the production of cordierite, is again found to have taken place along the granite margin in the neighbourhood of Bonawe, and along the western slopes of Beinn Duirinnis, on the north side of Loch Etive, and it may here be stated that a cordierite-hornfels has also been observed near the Ben Cruachan type of granite in the Glen Etive area, in Sheet 53. In this latter area, however, the contact zone is not so well marked as it is further to the south-west, since evidently here the sediments had been affected by the forces of dynamic or regional metamorphism to a far greater degree, and were already in the condition of highly crystalline schists previous to the intrusion of the granite. There can be no doubt, however, that the different varieties of hornfels above described owe their peculiar and characteristic features directly to the contact-action which took place during the intrusion of the Ben Cruachan granite.

*The Effect of the Granite upon the Andesitic Lavas of Lorne and their Associated Sediments.*—The andesitic lavas of the Lorne plateau are seen to terminate abruptly along the south-western margin of the north-western half of the Pass of Brander, at a distance of about three quarters of a mile from the Ben Cruachan granite. In the Blackmount district it is known that volcanic rocks of the same age as those of Lorne are invaded and altered by a continuation of the Cruachan granite. It would be interesting, therefore, if a similar alteration could be found to have taken place in the Lorne area also. It does not appear, however, that the lavas in this area, as at present exposed, have been affected to any great degree by the intrusion of the granite, and this is doubtless in great part due to the distance by which they are separated from the granite margin.

Beneath the lavas in this area there lies sometimes a conglomerate and sometimes a breccia, consisting of fragments of the underlying schists, such as black slate, limestone, phyllite, and epidiorite. As this basement bed is traced towards the Pass of Brander, it seems to undergo a gradual and perceptible change, as if it had suffered a general induration. This alteration is especially noticeable at a distance of about half a mile from the Pass. The rock is not exposed, however, near enough to the granite to afford the means of deciding whether this induration is due to contact-alteration or not. Above the conglomerate, at from a half to a quarter of a mile from the Pass, there are some banded and laminated beds resembling ash or tuff, which show this induration in a marked degree, and they are frequently full of greenish streaks and patches from the presence of epidotic material.

Above these banded beds come the normal pyroxene-andesites. They, too, are much indurated, and are very refractory under the hammer. The microscope shows that they are augite-andesites of a basic variety, and that if they have undergone any contact-alteration, it can only be slight. The abundance, however, of small granules of pyroxene seen in the ground-mass [9031 and 9032] seems unusual. Probably these rocks are too far from the granite margin to show contact-alteration to any great degree. In the case of the Blackmount area, contact phenomena are not perceptible in the andesites at a distance greater than about a quarter of a mile from the granite, so that it would not be surprising if such phenomena were entirely absent at a distance of three quarters of a mile, such as we have in the present instance. But, although any very decided contact-alteration cannot be detected with the microscope in these andesites, it is very significant to note that these rocks, up to a distance of about a quarter of a mile from the Pass of Brander, are frequently seen to be traversed by small veins and bands, a few inches in breadth, of a rock allied to porphyrite, but approaching rather to microgranite in texture, a phenomena which strongly suggests that the surrounding rocks were at a high temperature at the time of the intrusion of these microgranitic veins.

In the railway cutting close to the Awe viaduct, we find intercalated in the andesites a band of laminated shales and grits, and

in these sedimentary beds the induration is very marked. The shaly beds have been hardened and the different laminae have become more or less cemented together, so that the rock does not tend to split up along them so readily as in its unaltered state. The coarser and more siliceous beds have the appearance and fracture of quartzite rather than grit. The granite is not more than three quarters of a mile from these beds, a distance at which it may well have indurated the sediments without appreciably affecting the andesitic lavas, since we know that sedimentary rocks are usually affected by thermo-metamorphic agencies to a greater distance than rocks of igneous origin.

H. K.

*Contact Action of the Glen Fyne Granite.*—The schists bordering this granite along the slopes of Glen Fyne were evidently in an advanced stage of crystallization before the granite intrusion. It is probable, therefore, that beyond induration contact action has been slight. While actinolite, biotite, and garnet are abundant in the neighbourhood of the granite, the persistence of these minerals in tracts far removed from that mass precludes their being assigned to contact phenomena. It is possible, however, that some of these minerals may have been so produced, but if so there is no means of deciding to what extent.

*Contact Action of the Granites of Beinn Bhuidhe.*—On the ridge of Beinn Bhuidhe occur two small irregularly-shaped masses of a medium-grained and somewhat acid type of granite. This ridge, however, and its northern slopes show considerable hornfelsing, altogether incomparable to that likely to have been effected by these small granites. It is probable, therefore, that they indicate the existence of a much larger mass lying close below the surface.

One of these granite masses on the northern flank of Beinn Bhuidhe has veined a lamprophyre dyke upon which it has effected marked contact alteration. A section taken close to the contact with the granite vein shows that the lamprophyre now consists essentially of small scales of contact brown mica and water-clear plagioclase [8467]. Slightly farther from the vein [8468] there are still signs of contact action, while the original crystals and crystalline aggregates of the hornblende of the lamprophyre are seen.

*Contact Action of the Kentallenites of the Beinn Bhuidhe District.*—In this area occur two bosses of kentallenite, one situated at An Sithein and the other in the Brannie burn. The former, which is little more than a quarter of a mile in length and about one-sixth of a mile in width, has been intruded into the Ardrishaig series—a zone of calcareous sericite schists. Here the regional type of metamorphism is less intense than that bordering the small granite intrusions of Beinn Bhuidhe, and the kentallenite mass, notwithstanding its small size, has produced a well-marked aureole of contact metamorphism. For about 20 yards from the limits of the kentallenite the phyllites have been conspicuously hornfelsed, but no visible contact minerals have been produced.

The kentallenite of the Brannie burn is slightly larger and has been intruded into the garnetiferous mica-schist band. This intrusion has produced an aureole of hornfels with a width of from 15 to 20 yards. The original garnets, however, of this stratigraphical zone are included within the hornfels, which is therefore garnetiferous. The garnets, however, are brighter in colour and fresher within the aureole, and have either been partially reconstructed or else the contact action has enabled them to resist disintegration. A rock slice [8470] shows a knotted hornfels. It is a fine-grained dark slate, which has developed a knotty structure by the formation of clusters of scales of deep brown biotite. The slate itself consists of pale colourless mica mingled with a brownish biotite and crossed by parallel lines, grains of iron oxide, and in some bands it is more quartzose. J. B. H.

*Lismore Island.*—The small igneous masses on Lismore are surrounded by aureoles of metamorphism which vary in breadth with the character of the altered rock. Narrowest in the purer limestone, the aureole broadens out in the impure limestone and appears to be widest in the black schist. The last-named rock is altered to a dark compact hornfels. Impure limestone becomes a banded calc-silicate-hornfels, whilst purer limestone is metamorphosed to a greenish or greyish granular marble, sometimes containing numerous small pinkish garnets on approaching the igneous rock. H. B. M.



## CHAPTER XI.

### CARBONIFEROUS.

A small patch of sedimentary rocks, noticed long ago by Macculloch, is found resting upon the Lorne andesitic lavas at the Bridge of Awe, at the north-west end of the Pass of Brander. It consists of thin bands of conglomerates, overlain by from 40 to 50 feet of pinkish and variegated marls, purple shales, and pale sandstones. The beds are well exposed on the right bank of the river Awe below the bridge, and may be followed beneath the bridge along the left bank as far as a small island which is seen in the river immediately above the bridge. At their lower end, about half-way between the Bridge of Awe and the railway viaduct, these beds appear to have been faulted down against the andesitic lavas.

The conglomerates which form the lower part of the series consist of rounded pebbles of quartzite, vein-quartz, and andesite, the latter evidently derived from the eroded floor of the underlying andesitic lavas. There is also a considerable proportion of derived volcanic material in the lower beds of sandstone. It is evident that there is a considerable unconformity between these sediments and the underlying lavas of Lower Old Red Sandstone age. In fact, there must be either a great stratigraphical break at their base, or an upward passage from the volcanic into the non-volcanic rocks, in which case there would be evidence of a second and younger volcanic series, like that of the Campsie Fells, and an unconformability would probably be found to exist between this series and the older lavas of Lorne. There is no evidence, however, of any break in the continuous succession of the Lorne lavas, which can only be regarded as representing one series, belonging to the Lower Old Red Sandstone period. The unconformity is doubtless at the base of the conglomerates which rest upon the denuded surface of the lavas, and we evidently have here a small outlier of Carboniferous sedimentary rocks.

The stratigraphical evidence of the age of these beds, however, would hardly be decisive without some palæontological evidence in addition. These strata were formerly regarded as belonging to the Old Red Sandstone, though no fossils had ever been obtained from them. During the progress of the mapping of this district, Mr. D. Tait was instructed to make a careful search for fossils in the more shaly beds, and his labours were rewarded by the discovery of a number of organisms, sufficient to show that the strata in question do not belong to the Old Red Sandstone, but to the

Carboniferous system—a fact of great interest in regard to the geological history of the West Highlands.

The specimens obtained included a small number of fossil plants, which, however, were unfortunately in a fragmentary state. These were submitted to Mr. Kidston, who found that they consisted of stems, rootlets, a fern rachis, and a calamite stem, which last he referred to *Asterocalamites scrobiculatus*, Schl. While of opinion that the plants have a Calcareous Sandstone (Lower Carboniferous) facies, Mr. Kidston is certain that they cannot belong to the Lower Old Red Sandstone. A further point in favour of the Carboniferous age of these strata is that a small patch of plant-bearing Carboniferous rocks was detected by Professor Judd\* on the east shore of the Sound of Mull near Ardtornish, a distance of only 20 miles to the W.N.W. of the strata at Bridge of Awe.

Another piece of evidence in favour of the Lower Carboniferous age of the Bridge of Awe beds is afforded by the occurrence of the cast of a small modioliform shell on one of the specimens with rootlets [T. 3257], which was determined by Dr. B. N. Peach. This form, though badly preserved, is almost identical with some varieties of *Modiola macadami*, Portl., one of the commonest shells of the Cement-stone group of the Lower Carboniferous series in Fife, Liddesdale, and the North of Ireland. Three varieties of the shell are figured in Portlock's "Geology of Londonderry and Tyrone."

H. K.

\* *Quart. Journ. Geol. Soc.*, vol. xxxiv., pp. 684-685.

## CHAPTER XII.

### FAULTS.

The central and eastern portions of the area embraced by the present sheet is traversed by two main lines of faulting. The one coincides with the Pass of Brander and Glen Salach, and the other coincides with Glen Strae and the trend of the north-eastern end of Loch Awe.

That the remarkable gorge of the Pass of Brander coincided with a line of fracture has long been thought highly probable, and an examination of the ground shows at once that this is the case. Signs of faulting are evident in many places along the side of the high road, and in the railway cutting between the Falls of Cruachan and the Bridge of Awe. The rocks are seen to be highly shattered and discoloured, and fault-breccia is seen in many places. The same line of fault is continued on the opposite side of Loch Etive, past Blarcreen, up the Esragan burn, and over the watershed into Glen Salach. It is lost sight of beneath the superficial deposits at the foot of Glen Salach, but it may possibly be continued on the north side of Loch Creran along the Strath of Appin. The pass at the head of Glen Salach shows precisely similar features to those of the Pass of Brander. Thus, on its west side we have the crags of the Lorne andesites of Benderloch, and on the east side the older schists which skirt the western boundary of the Ben Cruachan granite.

Along this line of fracture the andesites of Lower Old Red Sandstone age have been faulted down against the much older schists which cling to the southern and western slopes of the granite hills. There is no means of estimating the extent of the downthrow, but it is probably very considerable. The faulting is of later date than the period of the porphyrite dykes, as many of these are seen to be shattered and brecciated on both sides of the Pass.

Another well-marked line of fracture follows a straight course running due north and following the margin of the granite about half a mile east of Blarcreen, on the north side of Loch Etive. This line is rather a line of smashing than of actual dislocation, as it smashes the granite and its associated veins, but does not appear to displace the rocks to any great extent relatively to one another. It follows a due northerly course as far as the eastern slopes of Beinn Bhreac, and then runs in a north-easterly direction as far as the northern boundary of the map. Deep gullies lined with shattered rock have been formed along its course, and narrow cols in the elevated ridges through which it passes.

The Glen Strae fault follows the course of the glen and is well seen in several places in the river Strae. It does not follow the entire course of the river, but crosses the col on the west side of Beinn Charn, and thence continues in a straight north-easterly course to the eastern margin of the map. The garnetiferous mica-schists and hornblende-gneiss of the Blackmount are seen in the north-east corner of the map to be cut off abruptly along this line and to be faulted against the granulitic schists of Moine type. When traced further to the north-east, outside the limits of the present sheet, this fault traverses the Moor of Rannoch, where it faults the granite, and is found to be continuous with the fault which follows the line of Loch Laidon and is continued as far as Loch Ericht.

In the area on the west side of Glen Strae there are numerous small but probably insignificant faults, mostly with a general north-west and south-easterly trend, and deep gullies and chasms have been formed in the hillsides along their course. The extent of the dislocation which they cause, however, is not seen, as they pass through homogeneous rocks.

In the granite area lines of smashing and crushing are fairly common, though they are not usually traceable for any great distance. They usually form deep chasms and clefts, which are occupied by small streams. The walls of some of these clefts often show crushed and slickensided rock-surfaces, but probably some of the smaller clefts may owe their origin merely to the widening of joint-features. Several of these chasms may be well seen on the precipitous eastern face of Beinn Trilleachan, on the west side of the upper end of Loch Etive.

In the Ben Cruachan area there are several east and west lines of faulting or smashing, which are often occupied by dolerite dykes. Many of the narrow cols between conspicuous heights along the southern spurs of Ben Cruachan coincide with these lines of weakness. Thus we have Lairig Torran separating Beinn-a-Bhuiridh from the higher points to the north, and Bealach-an-Lochan separating Meall Cuanoil from the highest point of Ben Cruachan. These features, due to lines of weakness, are not seen on the north side of the main ridge of Ben Cruachan, where the northern ridges or spurs run out from the main ridge with a uniform slope into Glen Noe.

In the Lorne volcanic plateau small faults and lines of smash in the andesitic lavas are very common, but none of these appear to displace the rocks to any great extent. There are two principal sets, one with a north-east and south-westerly trend, and the other with a north-west and south-easterly course, coinciding with the direction of the Tertiary dykes, and of these the latter set would appear to be the younger of the two. H. K.

*Oban and Kilmore District.*—In the Oban and Kilmore district the two systems of faults referred to above are well displayed, as they have the effect of cutting up the rocks of the volcanic plateau into a series of rectangular blocks. The earlier of the two sets,



with a north-east and south-west trend, occur at almost regular intervals, and although their displacement seldom exceeds three hundred feet, they extend laterally for great distances. In the vicinity of Oban their downthrow is persistently to the north-west, so that, notwithstanding the constant south-easterly dip of the strata, the basement beds of the Lower Old Red Sandstone series are repeatedly brought to the surface, as may be seen from the map (Sheet 45) and the horizontal section (fig. 1). B. N. P.

In the area lying to the west of Loch Awe and south of the Strath of Orchy, the most important dislocation is the great north-north-east fault of Glen Fyne, which, beyond the limits of this sheet, has been traced far into the Central Highlands in the direction of Tyndrum and Loch Lyon. This fault, which runs along the bed of Glen Fyne as far south as Inverchorachan, skirts the western margin of the Glen Fyne granite, but has ruptured a felsite intrusion which is associated with the latter. A fault of similar trend but of smaller extent occupies the bed of Glen Shira. There are minor dislocations of the same trend scattered over the area. Another system of faults, and probably of later date, trend between north and west with an average strike of about north-north-west. These are perhaps most numerous along the eastern slopes of Glen Fyne. To the south of Meall-nan-Tigearn the boundary of the garnetiferous mica schist group has been thrown out of its course for over a quarter of a mile by a fault of this system. In the area between Dalmally and Beinn Bhalgairean some minor faults occur with a trend approximately north and south. J. B. H.

## CHAPTER XIII.

### GLACIAL AND RECENT DEPOSITS.

The present map may be said to be characterised by the relatively small amount of superficial deposits belonging to glacial and recent times, compared with the large extent of area over which bare rock is either at the surface or very close to it. The glens, as a rule, are narrow and the hills bold and steep, so that surface accumulations would be apt to be rapidly carried away in a climate characterised by a high rainfall.

#### i. GLACIAL DEPOSITS.

There is indeed overwhelming evidence throughout this area of the great extent to which the whole country has been subjected to glaciation. Everywhere along the sides of the glens, along the hill slopes, and along the shores of the lochs, the smooth, polished, and striated surfaces, and *roches moutonnées*, bear striking testimony to the work of the ice, while the morainic mounds filling the glens indicate in an unmistakable manner the action of the huge valley-glaciers which formerly occupied the country. By far the greater part of the glacial phenomena of this area are entirely to be attributed to the period of the later glaciation—a glaciation which in this part of the country was so thorough as to leave little trace behind it of the more extensive glacial phenomena which preceded it.

1. *Direction of Ice-flow.*—Throughout the more mountainous portion of the area to the north-east of the Pass of Brander fault, the direction of the ice-flow usually coincides with the direction of the major glens, and conforms generally to the contour of the ground. The smaller glaciers belonging to the declining phase of glacial times were evidently of a strictly local character and radiated from the corries of the higher hills.

In this area the observations upon striated surfaces, erratic blocks, and the distribution of the morainic material, show that the largest glaciers had their sources of supply in the high ground to the north-east, and thence followed a general south-westerly course. Thus, from the elevated north-eastern area two main glaciers flowed down towards the lower and more open area to the south-west. One of these followed the course of Glen Etive and Loch Etive as far as Bonawe, whence it tended to spread out over the less elevated ground. The numerous erratics and ice-scratchings seen along the shore of Loch Etive gives ample evidence of the direction followed.

In the area about the western portion of the loch, where the ground is less elevated, the direction of the striæ is frequently slightly north of west. Numerous blocks, however, of the characteristic Bonawe granite are found about Oban, and these boulders have travelled in a direction slightly south of west, Bonawe being on the north shore of Loch Etive, 13 miles E.N.E. of Oban. The slight northerly deflection to the west of Bonawe was evidently brought about by the Ben Cruachan ice pressing upon the Loch Etive glacier from the south-east. In the upper portion of Loch Etive the Glen Etive glacier was evidently squeezed into narrow limits in the confined space between Ben Starav and Beinn Trilleachan, and slightly further along its course this glacier was joined by the smaller ice-streams from Glenkinglass and the small glens on the west side of the loch; consequently one would expect that in this part of its course the ice would have exerted its maximum power of erosion, owing to the enormous lateral pressure to which it was subjected. And we find in fact that this portion of Loch Etive is considerably deeper than it is further south-west at Bonawe, or at its exit at Connel Ferry, and the evidence certainly tends to show that this deepening of the upper portion of the loch was due to the eroding action of the ice filling the loch-basin.

Further to the east a much larger glacier flowed down Glen Orchy from the high ground about the Blackmount and Moor of Rannoch, and received in its course a large tributary glacier coming down Glen Lochy on the east, and further on was joined by the Glen Stræ ice on the north. The confluence of these three glaciers evidently formed a large and powerful mass of ice, which swept down to the south-west along the line of Loch Awe, spreading out over the comparatively low ground on either side to a considerable extent. At one time the entire area to the east of Loch Awe was evidently over-ridden by ice from the north-east, as we find morainic drifts, with boulders of Glen Orchy types of rock, in the hollows of the higher parts of many of the hills. At a later period it appears that a portion of the Beinn Bhuidhe ice travelled westward across Glen Shira and over the low col separating that glen from the drainage basin of the Claddich river, and thence turned southward, by the pressure of the Loch Awe ice, into Glen Aray. The larger portion of the Beinn Bhuidhe ice doubtless followed the line of Glen Shira on the one hand and of Glen Fyne on the other hand, while the upper portions of these glens received glaciers from the high ground about Meall nan Tigearn and Ben Laoigh, further to the north-east.

To the west of Loch Awe, the ice formed by the confluence of the various glaciers from the more mountainous ground over-rode the entire area between Loch Awe and the western part of Loch Etive, with a general direction slightly south of west. Local variations in the direction of flow are often met with, but are mainly due to the configuration of the ground.

The Glen Orchy and Glen Stræ ice evidently spread out in the Loch Awe area and forced its way some distance to the west, as we find boulders of the Glen Orchy kentalenite and the Glen Stræ

augite-diorite on the hills to the south of Loch Scamadale. Granite boulders are also occasionally met with here, but increase enormously in quantity in the ground further north about Loch Nell and Oban.

2. *Boulder Clay*.—Only a very small quantity of boulder clay is known to occur in the present map, and it does not appear that any part of this belongs to the earlier period of glaciation, but rather to the later period of the valley-glaciers. In the Kilchrenan area boulder clay is often met with in the depressions and hollows, but is of no great thickness. It is seen to the west of Kilchrenan village and again further to the south-west between Kilchrenan and Coillaig. It is a stiff, dark, and sometimes yellowish clay, and contains polished and striated boulders. At Braglenbeg, near the head of Loch Scamadale, a gravelly clay is seen containing well-scratched stones. Again, to the east of Dalmally, in the morainic area on the south side of the Strath of Orchy, some of the small streams have cut their way down into a stiff clay with polished and scratched stones, probably representing the fine detritus deposited by the glacial streams connected with the Glen Orchy and Glen Lochy glaciers.

H. K.

In the Oban and Kilmore districts a sparse deposit of boulder clay is found in the hollows between the rocky knolls which characterise this region, but whether the boulder clay represents the ground moraine of the great ice sheet or that of the later confluent glaciers is difficult to determine. The presumption is that it belongs to the later period. The deposit, which is always thin, is normally a greyish or reddish stiff clay with well-striated boulders of quartz-schist, garnetiferous mica-schist, granites and porphyrites from the Highland area to the east, and of the volcanic and other igneous rocks of the Lorne plateau, which outnumber all the others put together.

B. N. P.

*Lismore Island*.—The drift is represented by a stiff boulder clay which spreads over the floors of the hollows between the limestone ridges and extends up the gentler slopes. It rises into hummocks in the depression near Park, and again in the valley above Fennacrochan. The matrix of the clay is, at the north end of the island, greyish in colour, whilst further south it becomes nearly black. The change appears to be gradual, and is doubtless due to the grinding up of the limestone and its incorporation in the clay. Limestone pebbles are also more abundant in the clay towards the south-west. Amongst the boulders in the clay, most of which must have come from the mainland, the following were noted:—Quartzite, schists of the Moine type, porphyrite (from the dykes of Old Red Sandstone age), arkose (similar to that of Old Red Sandstone age in the Great Glen), many varieties of granite and diorite, and an agglomerate similar to one found amongst the volcanic rocks of Glencoe and Ben Nevis. Large boulders of granite and quartzite occur scattered over the hills at all altitudes.

The direction taken by the striæ is very variable, but on the whole they appear to indicate a general south-westerly movement of the ice. On a small island west of Eilean Ramsay, a set of striæ running



N.  $5^{\circ}$  E.—S.  $5^{\circ}$  W. are crossed by a later set running from N.  $70^{\circ}$  E. Most of the striæ are found on the dykes and are preserved almost always between tide-marks. H. B. M.

3. *Moraines*.—The essential and characteristic glacial deposits of this area are certainly formed by the extensive accumulations of morainic materials brought down into the glens and straths by the later valley-glaciers, and left after their retreat as indisputable evidences of their former presence. Nowhere perhaps are these deposits better seen than in the glens and hollows of the mountainous country in the north-eastern portion of the map. It is perhaps along the lower portions of the glens and on the lower slopes of the hill-sides that the morainic drift has mostly been accumulated, and it is here that the characteristic mound-like forms of the deposits are best developed. When traced up to the heads of the glens this mound-like form is less pronounced and often gives place to a more even and uniform rubble-like accumulation, mingled with scree material from the upper parts of the corries. There is frequently also a more high-level and flat type of moraine, consisting of loose angular gravelly material, found strewn over the higher slopes and corries. The mound type of moraine, however, frequently passes uninterruptedly from the head of one glen to another across the intervening divide, where it is of no great height in comparison with the average level of the glen. Thus there is a continuous series of moraines from the head of Glen Stræ across the col on the east side of Beinn Charn down into Allt Coire Bhicar into Glen Orchy on the east, and into Gleann Fuar on the north-east. The moraines, also, of the upper portion of Glen Kinglass are carried eastward into the area about Loch Dochard and Clais-gobhair, and so are continuous with the train of mounds running down to Loch Tulla at the head of Glen Orchy. Doubtless this represents a local easterly extension of the confluent glaciers from the higher hills of the Blackmount. A similar continuity of moraine material is seen further south between Glen Shira and the head of Glen Fyne, and from the west side of Glen Shira over the low col between that glen and the upper part of the Cladich River. The pressure of the Beinn Bhuidhe glacier apparently pushed the upper Glen Shira ice over this divide, thus causing it to flow down westward towards Loch Awe.

A fine series of moraines was accumulated at the confluence of the Glen Stræ, Glen Orchy, and Glen Lochy glaciers, and cover a considerable area of the more low-lying ground on the south side of the Strath of Orchy, whence they are continued up into Glen Orchy and Glen Lochy. The characteristic mound-forms are here most beautifully developed, and sections of them may be studied along the side of the railway in Glen Lochy. They usually consist of coarse or sometimes fine gravels, indiscriminately mixed with boulders of all sizes.

In the north-western portion of the map the slopes about the upper end of Loch Creran are singularly free from morainic

material, the sides of the hills being very steep and flanked by smoothed and striated rock-surfaces.

In the Lorne volcanic plateau morainic drift is found throughout the entire area in the hollows and depressions among the hills, mostly as small patches, and especially in the glens near the western seaboard. Morainic mounds are well seen in Glen Lonan and in the two small glens which unite just above the head of Loch Scamadale. The contents of these moraines indicate that they were evidently derived from the extension of the large glaciers which flowed from the mountainous country to the north-east.

H. K.

*Oban and Kilmore District.*—The evidence supplied by the *roches moutonnées*, striated surfaces, erratics, and the disposition of the moraines and fluvio-glacial deposits points plainly to the great confluent glacier from the Highland glens having passed over the Oban and Kilmore region in a westerly direction during the period of the later glaciation.

The striæ to be seen on the schistose rocks exposed between tidemarks at Oban vary from  $10^{\circ}$  to  $25^{\circ}$  north of west, while the direction of those found on the plateau to the east of that place are from  $10^{\circ}$  to  $30^{\circ}$  south of west. To the south of Loch Nell the striæ observed on the high plateau point nearly due west, but in the valleys which intersect the plateau the striæ conform more or less to their trend.

The *roches moutonnées* have their smooth faces directed towards the east.

Terminal moraines marking the retreat of the ice are observable both on the high plateau and in the intersecting valleys. Those found on the high plateau stretch mostly in a north and south direction across the block of high ground into which it is cut up by the valleys. Those found flooring the valleys occur in such a way as to show that lobes of ice passed down the valleys after it had disappeared from the intervening portions of the plateau. These phenomena are well exhibited in the Lonan, Loch Nell, and Feochan valleys, in the Scamadale and Euchar valley, and the intervening high plateau, the moraine stuff being in great part composed of schists and granites from the Highlands. B. N. P.

4. *Erratic Blocks.*—In the more mountainous portions of the area erratics and perched blocks are not nearly so numerous as they are over the lower ground to the south-west. Very few have been observed at an altitude much over 2000 feet. They consist mainly of granite, and have been derived evidently from the continuation of the granite masses to the north-east. Thus, over the tract characterised by the Ben Cruachan type of granite, erratics of the coarse Glen Etive type are fairly common. In the district near the head of Loch Creran large boulders of a coarse kentallenite and coarse augite-diorite occur, which most probably were brought down by the later valley ice from the upper part of the glen, but at present the parent-rock of these boulders has not been identified with certainty.

It is when we come to the less elevated ground to the south-west that one is struck by the enormous quantity of erratics strewn freely over the hills and glens, and distributed in a striking manner according to the direction of flow and distribution of the glaciers which transported them from their homes.

In the Benderloch area, situated between Loch Creran and Loch Etive, the entire surface of the ground is thickly strewn with granite boulders of all sizes, and probably almost every variety of the Ben Cruachan and Glen Etive mass is here represented. A large boulder of calcareous schist—sufficiently imposing to have been deemed worthy of the local name of Clach Dhonuill—may be seen in this area a short distance to the east of Dubh Loch Mòr, and was probably derived from the calcareous schists known to occur in considerable quantity in Glen Creran.

Boulders of the Ben Cruachan and Glen Etive granites are found over the entire area of the Lorne volcanic rocks on the south side of Loch Etive as far as Lochaweside, but they diminish considerably in numbers as one approaches the Loch Awe basin and give place to the metamorphic and other types of igneous rocks of the Glen Orchy area. About Taynuilt and Bonawe the granite erratics are very numerous and often of large size. Thus an enormous boulder of the Glen Etive granite—locally named Clachmanessa—forms a conspicuous object on the shore of Loch Etive in Airds Bay, while a boulder, not much inferior in size and consisting of Ben Cruachan granite, is seen about a mile east of Taynuilt, and is locally pointed out as “Rob Roy’s Putting Stone.”

Everywhere between Taynuilt and Oban similar boulders are met with, and are again exceedingly numerous around Oban and between Oban and Loch Feochan. In the Oban district they are often of large size and sometimes must weigh at least 10 tons. Further south, in the area about Loch Scamadale, the granite erratics become comparatively scarce, as that tract lies in the province of the boulders which were brought down from Glen Strae and Glen Orchy. A certain proportion, however, of granitic erratics doubtless found their way down to the lower ground by way of these glens from the eastern portion of the granitic area, and these boulders are certainly numerous on the shores of the north-eastern part of Loch Awe. The granite boulders, however, of the Loch Awe area are invariably of the Ben Cruachan type, the boulders of the Glen Etive type of granite being confined to the area of distribution of the Glen Etive ice.

The distribution of some of the igneous boulders from Glen Orchy and Glen Strae is rendered comparatively easy to follow by their distinctive and easily recognisable characters. Thus the kentallenite which occurs on the west side of Glen Orchy, near the eastern margin of the sheet, has been the parent of numerous erratics which may be traced down Glen Orchy to Dalmally, and thence for many miles in a west-south-west direction. Large boulders of kentallenite occur in the Strath of Orchy and over the morainic area to the south. They are again common in the



Kilchrenan area, and have been occasionally found among the hills to the south of Loch Scamadale. With the exception, however, of the erratics occurring a mile or so to the south of the Strath of Orchy, kentallenite boulders of Glen Orchy type have not been found to the east of Loch Awe. A large isolated boulder of kentallenite lying near the head of Glen Aray has probably been derived from one of the exposures of that rock in the Ben Bhuidhe district.

Another characteristic igneous rock from the north-east, namely, the augite-diorite of the west side of Glen Strae, is frequently met with among the erratics in the Kilchrenan area, and has been traced as far as the south-west corner of the sheet. In the more immediate neighbourhood of the parent rock boulders of this characteristic augite-diorite are exceedingly numerous, both as large erratics and smaller blocks. Erratics are often found at a greater height than that at which the parent mass is situated. Thus, close to the Glen Orchy mass of kentallenite we find a well-marked train of boulders, which may be followed in a south-westerly direction up a branch of the burn in which the rock occurs, and up the hill slopes between that burn and Glen Orchy to a height of nearly 1500 feet, or about 600 feet above the exposed parent rock.

In the Loch Awe area we also find occasional erratics of dolerite derived from the east and west dykes to the north and east of Dalmally. Large boulders of garnet-schist are also encountered occasionally on the hills to the south of Glen Orchy and Glen Lochy, and closely resemble the garnetiferous schists which occur on the high ground to the east. H. K.

*Oban and Kilmore District.*—The most marked erratics are granites from the Cruachan massif, trains of which cross the area in such numbers that, in spite of their having supplied material for the ashlar work of most of the buildings of the region, they still form conspicuous objects in the landscape, especially in the high ground to the north of Loch Nell. South of that loch they decrease in number and become scarce south of Scamadale. In perhaps fewer number and of smaller size occur fragments of highly altered quartz-schist and silvery garnetiferous mica-schist, that had their origin from still further within the Highlands than most of the granite. One of the most striking evidences of the westerly movement is supplied by an exposed portion of a large porphyrite dyke occurring within the area on the hill top to the south of Glenamacrie in Glen Lonan, from which a conspicuous train of boulders can be traced to Torr-an Tuirc near the head of Loch Nell. B. N. P.

5. *Fluvio-glacial Gravels.*—Stratified gravels and sands forming well-marked terraces may be well seen along the northern shores of Loch Scamadale, about nine miles S.S.E. of Oban. These deposits rise up to 30 feet above the loch, which is 221 feet above sea-level. They continue along the glen below the loch, along the sides of the Euchar River, which they follow until they finally merge into the 100-feet beach on the south side of Loch Feochan, in Sheet 44.



Associated with these terraces are more recent gravel deposits formed out of them by the action of the stream. The terraces of stratified materials were very probably of fluvio-glacial origin, the site of Loch Nell being occupied by a lobe of ice during their deposition. Other deposits, possibly of similar origin, may be seen in the valley between Oban Cemetery and Dunstaffnage Castle, where large accumulations of sand and gravel rise to over 100 feet above sea-level, and nearly all the material is obliquely laminated. Again some thick deposits of fine sands and gravels, forming a terrace above the 100-feet contour-line, occur along the Lusragan Burn about a mile and a half south of Connel Ferry. The terrace here indicated is probably due to the overflow water from Glen Lonan at a period when the Loch Etive glacier, during its decrease, sent a lobe down the Lonan valley into Loch Nell, for these fluvio-glacial deposits of sand and gravel, heaped up into mounds, extend from the Dig Bharrain, the upper part of the Lusragan valley, across the col to Strontailier, at the foot of Glen Lonan, in such a manner as to indicate that they were laid down along the margin of the ice during its decrease.

The "serpent" mound at the foot of Loch Nell, supposed to be artificial, is the remains of the gravelly moraine formed at the end of the Lonan and Loch Nell glacier during its retreat in 100-feet beach times, while the fluvio-glacial gravels described as occurring on the col to the north of the head of the loch point to a time when the melting water from a lobe of that glacier escaped across the col into the valley of the Lusragan. The fluvio-glacial gravels seen along the roadside between Pennyfuair and Oban were in all probability formed when the ice had retreated so far that the water from a lobe of the Loch Etive ice filled the lower part of this valley and escaped across into Oban at the time when the land stood a hundred feet lower than at present, for on the retreat of the ice the sea evidently had access to the valley, as the 100-feet beach is here partly cut out of these deposits.

B. N. P. and H. K.

## ii. RAISED BEACHES.

The remarkable series of raised beaches for which the west coast of Scotland is so well known, and some of which date back to the glacial period, are well developed in the western portion of the sheet. These terraces extend along both shores of Loch Etive. They are well marked on the north side, where the Moss of Achnacree, an expanse of peat about two square miles in area, lies upon the sands and gravels belonging to the 50-feet beach. On the same side of the fjord, between Achnaba and Ardchattan, the 100-feet beach is well marked, though on the opposite side it is not so conspicuous. It is, however, well seen along the railway line to the south and south-west of Achnacloch. This beach is again well developed at Taynuilt, the railway station being situated upon it.

The more recent beaches are seen on both sides of Loch Etive from the mouth of the loch up to Bonawe, and again further to the

north-east at the mouth of Glen Kinglass and Glen Liver. Thus the 50-foot beach is well seen between the rivers Nant and Awe, near Taynuilt. In the Benderloch area the same beach, besides underlying the moss of Achnacree, covers a considerable area to the north of Ledaig. In the Loch Creran area these later beaches are seen at the foot of Glen Salach and on the south side of Creagan Ferry.

H. K.

*Oban and Kilmore Region.*—Near Kilmore the 100-foot raised beach occupies a well-marked terrace at the foot of Loch Nell and in the angle between the Feochan Mòr and Feachan Bheag rivers. The terrace, partly as a rock-notch and partly covered by beach materials, can be traced to the south-east side of Loch Feochan for some distance from its head, while corresponding high cones of alluvium are thrown on to it by the side streams.

Remains of this terrace also occur in the upper part of Oban, near the Bowling Green, and at the foot of Glen Crutten. It also occurs to the north-east of Oban, near the head of the valleys that end in Dunstaffnage Bay and the Camas Bruaich Ruaidhe. It forms a considerable breadth of country in the valley of the Lusragan, and remains of the beach are found round the chain of the Black Lochs, and conspicuous fragments of the terrace are found near Achnacloich, further up the shore of Loch Etive.

Evidence has been given to show that the 100-foot beach found near the foot of Loch Nell was laid down while a lobe of the Highland ice still filled the site of Loch Nell. The valley of the Feochan Bheag, above Craigentaggart, supplies evidence of having been invaded by a similar lobe, for while below Craigentaggart there is a fine terrace of the 100-foot beach, moraine mounds form the floor of the valley beneath that level further up the valley. The present area affords evidence of the long duration of the 100-foot beach period, for it must have taken a considerable time for the ice to retreat from the Kilmore area so as to allow the 100-foot terrace to form as far up Loch Etive as Achnacloich.

B. N. P.

*Benderloch and Ardmucknish District.*—The most interesting raised beach deposit in this region consists of remnants of the 100-foot beach in the form of mounds of circumdenudation, locally known as the "Seabank," standing above the level of the lower beaches. The deposits constituting the mounds consist chiefly of laminated clays and sands with interstratified beds of fine gravel. At Shian Ferry these mounds reach an elevation of a little over one hundred feet. The deposit has suffered greatly from denudation, and at one time the row of hills must have been surrounded by the waters of the sea. There is no evidence that land ice shared in the work of demolition.

The following is a list of shells that have been collected from these deposits at high-water mark where the clays are well exposed. These have been determined by Mr. E. T. Newton, F.R.S.:—

*Echinus* sp. [spine of].  
*Serpula triquetra*, Mart.  
*Balanus porcatus* (?), *Da Costa*.  
 „ *tintinabulum*, Linn.  
*Cancer pagurus*, Linné.  
*Astarte borealis*, Chem.  
 „ *compressa*, Mont.  
 „ *elliptica*, Brown.  
*Cardium nodosum*, Turt.  
*Cyprina islandica*, Linn.  
*Mytilus edulis*, Linn.  
*Nucula nucleus*, Linn.  
*Nuculana pernula*, Müll.  
 „ *pygmæa*, Müst.

*Pecten islandicus* (?), Müll.  
*Tellina* sp.  
*Hydrobia ulvæ*, Penn  
*Lacuna vincta*, F. & H.  
*Littorina rudis*, Maton.  
*Natica alderi* (?) Forbes.  
 „ [operculum of].  
*Phasianella pulla*, Linn.  
*Rissoia membranacea*, Ad., var.  
*venusta*.  
*Thracia* sp.  
*Trochus ziziphinus* (?), Linn.  
 Chalk flint [not worked], with  
 micro-organisms.

E. B. B.

*Oban and Kilmore District.*—The 50-feet raised beach, the upper limit of which seldom reaches a height of 50 feet in the present region, is well developed at the head of Loch Feochan and up both branches of the valley, where its broad terraces are mostly covered by peat. Remnants of the beach are also found in the floor of Glen Crudden. The terrace of this beach, partly as a rock-notch with marginal sea caves, and partly covered by beach material, extends from end to end of Oban. The caves, some of which are still open to the light of day, bear evidence from their contents of having been inhabited at intervals from before historic times down to the present. This beach occurs on the north side of the area between Oban and Dunstaffnage, and fills part of the valleys opening on to Loch Etive between Dunstaffnage Castle and a point above Connel Ferry. It also forms a terrace of varying breadth along the south shore of Loch Etive from Connel to Rudha nan Carn and even further up the loch. Near Connel Ferry its storm beaches rise above the 50-feet contour line. Good sections of the coarse gravels were exposed at Connel Ferry Railway Station when the platforms were being made in connection with the construction of the Connel and Ballachulish Railway.

Fragments of terraces of raised beaches at a lower level than the above are found in the same localities where the fifty-feet beach is developed, marking shorter pauses in the general movement of elevation of the region.

B. N. P.

*Benderloch and Ardmucknish District.*—The raised beach indicated by the well-marked rock-notch in Ardmucknish rises to the approximate level of 50 feet O.D. There are great accumulations of storm beach gravels in connection with it, especially along the base of the cliffs that bound it to the east.

A second beach some fifteen feet lower has been cut in the platform of gravel belonging to the 50-feet beach, and still another but little above present high-water mark may be detected in the northern part of the peninsula.

E. B. B.

*Loch Creran District.*—On the north side of Loch Creran the 50-feet beach forms a well-marked feature, for during the period of its deposition the waters of the loch filled numerous narrow fjords in



the vicinity of North Shian and Rudha Garbh, where one is a mile long with narrow flat bottom and steep sides.

The whole of the level ground around Port Appin is formed by this deposit and extends up the Strath of Appin to Auchnacone House. On both sides of Airds Bay this platform is a rock shelf, and at Barriemore there is a well-defined beach which reaches up to 25 feet. On Eriska and at Balure both the 25 and 50-foot beaches are represented.

J. S. G. W.

*Lismore Island.*—The whole coast of Lismore within the sheet bears a well-marked terrace at an altitude corresponding to the 50-foot beach of neighbouring areas. The inner edge of the rock-shelf under the cliffs commonly varies in altitude from 30ft. to 36ft. above O.D. Though usually a bare rock-ledge it is sometimes covered by shingle, which contains pebbles of rocks similar to those found in the boulder-clay. No shells were found in the deposit. Unrearranged boulder-clay reaches down to this beach, and no evidence of any higher one was obtained. The cliffs bounding the beach are frequently hollowed out into numerous small caves, whose walls are covered by stalactite. At Sròn-na-Craoibhe, where the cliffs are absent for a short distance, there is a curved ridge of gravel, concave towards the sea, and formed of false-bedded sand and gravel. The gravel is essentially of the same composition as that found on the beach elsewhere. In cross-section the ridge has a long gentle slope seawards and a short steep slope on the landward side, where the drainage is obstructed and a peat-moss has formed. Similar, though smaller, ridges are found in analogous positions to the north and to the south of Port Ramsay. They appear to be storm-beaches of the "50-foot beach" period. A lower beach, which is distinguishable with difficulty from a more modern storm-beach, appears to be preserved only near Port Ramsay, where the coast is protected by small islands.

H. B. M.

### iii. ALLUVIAL TERRACES.

Alluvial terraces are usually well developed in connection with all the larger streams. Three main terraces can usually be mapped out, and occasionally minor terraces have been cut out from these main ones. Perhaps the best series of older river terraces are those developed in connection with the river Awe. These are well seen between the Bridge of Awe and the Pass of Brander, and at Inverawe House. On the west side of the river below Inverawe the second terrace merges into the 25-foot beach. A series of three terraces have also been mapped in the lower parts of Glen Creran, Glen Etive, and Glen Kinglass.

In the more mountainous portion of the area alluvial fans are well developed about the mouths of the larger burns. The large size of many of these detrital fans, *e.g.*, along the shore of the upper part of Loch Etive, and the coarseness of the material of which they consist, is very striking. But this is perhaps not surprising when we consider the great capacity for the transportation of material



possessed by the mountain-torrents during flood-time, and the enormous quantity of more or less loose material, in the form of talus débris and moraine matter, at their disposal. Thus, many of the higher terraces and more recent alluvial deposits consist largely of rearranged morainic drift. The work of the mountain-streams, moreover, is largely assisted by small tributaries which run over the bare granite, pitching at a high angle. Down these and down the numerous scree-gullies and stone-shoots lining the mountain-sides the water is poured in torrential cascades during times of heavy rainfall, pushing onwards and piling up enormous boulders as though they were small pebbles.

In this connection we may perhaps conveniently refer here to the effects of lateral erosion in the lower parts of the course of such rivers as the Etive, the Kinglass, and the Orchy. In the lower and wider portions of the valleys slight alterations in the courses of these rivers appear to be constantly in progress from year to year. The amount of this alteration may be appreciated by comparing the course of the rivers, as represented on the six-inch Ordnance maps, published more than 30 years ago, with the present courses of the rivers and the distribution of the alluvial plains. The terraces are seen to have been largely cut away in some places, while fresh alluvium is being laid down in others. The destruction of the terraces is naturally greatest at the convex side of a bend in the stream, and is doubtless due to the increased eroding and transporting power possessed by the river during flood-time, when this action may actually be observed. Such rivers as these rise rapidly, owing to the rapidity with which their tributaries bring down the water from the surrounding high ground, and also to the large areas which are now drained artificially into these streams by means of trenches. Hence they become exceedingly powerful agents of denudation during times of heavy rainfall. In many districts, as for instance in the Strath of Orchy, where the winter floods are often very heavy, the inhabitants are now obliged to construct stout palisades to protect the alluvial terraces, so valuable for agricultural purposes, from destruction. Near the mouth of the river Etive it was ascertained that the bank of the river along the outer side of a bend was being carried away at the rate of a foot or more per annum.

H. K.

*Oban and Kilmore District.*—In the Lorne volcanic plateau the principal streams are bordered by alluvial terraces for the most part cut out of the glacial and raised beach deposits. Thus, in the Euchar valley below Loch Scamadale the river terraces are carved out of the fluvio-glacial beds. Those of the Lonan and Feochan rivers are eroded partly out of the fluvio-glacial beds of Glen Lonan and the raised beaches below Loch Nell. The Dig Bharrain, in the upper part of the Lusragan, has drained what has been a loch resting on 100-foot beach deposits and now represented by a wide spread of alluvium.

B. N. P.

## iv. PEAT.

The only considerable peat-mosses which occur within the limits of the present sheet are those to the south of Connel Ferry and in the western portion of the Benderloch area. Immediately to the south of Connel Ferry a considerable thickness of peat is seen resting upon the 50-feet beach, and again, to the north of Connel Ferry, in Benderloch, in the Moss of Achnacree (said to be Ossian's "Plains of Lora"), we have nearly two square miles of peat resting upon the same beach. In fact, the spread of peat over the raised beaches of this area is one of the most characteristic features of these platforms. It is again well seen in the flat ground to the north-west of Beinn Lora, in western Benderloch. These peat-mosses probably began to grow not long after the sea retired from the terraces which they have overspread. The peat here reaches a maximum depth of rather over 10 feet, and immediately beneath it are found the sands and gravels of the raised beach. It is of a good quality for fuel, for which it is largely used by the poorer classes of the inhabitants of the surrounding districts. The surface of these tracts is now mostly covered by heather, while the peat itself contains numerous stumps, roots, and fragments of birches.

A comparatively thin covering of peat is frequently found over many of the alluvial flats. Thus we find peat covering some of the older river terraces, as in Glen Etive, Glen Kinglass, and Glen Orchy, and also the more recent alluvial flats at the junction of the Orchy and the Strae, near the head of Loch Awe.

Thick deposits of peat often occur in association with the silted-up portions of the lochs and lochans, and forming more or less level tracts among the hills, representing the sites of lochs which have become entirely silted up, partly by the importation of sediment and partly by the excessive growth and decay of various species of water-plants. Several examples of this type of peat-moss occur in the area about Kilchrenan. The flat peaty tract on the west side of Loch Tromlee, about a mile and a half north of Kilchrenan, is a good example of the extent to which this loch has become silted up within comparatively recent times; while about a mile to the east of Loch Tromlee we find another larger and older peat-moss, which may probably indicate the site of a former loch.

The formation of peat is again often largely associated with the drift-covered areas occurring in the broader depressions among the hills and in the wider parts of many of the glens. The peat thus often forms considerable tracts covering the morainic gravels and occupying the hollows and depressions between the numerous mounds or occasionally protruding knobs of rock. A considerable thickness of peat in this way occupies the hollow between Kilchrenan village and the farmhouse of Achnamady, and again similar deposits are seen in the morainic area to the west of Loch Dochard in the north-eastern corner of the map. In the former locality the peat is of good quality and is largely used in the district for fuel. In the mountainous portion of the area the peat covering

the morainic drift is frequently crowded with the roots and stumps of Scotch fir, and fragments of birch are also common.

In the more mountainous ground there is very little peat covering the upper parts of the hills, as these usually consist of sharp, rocky ridges, where only bare rock is exposed, or is covered merely by a thin coating of sandy soil supporting scanty heather and grass. But wherever the mountain-ridges broaden and spread out to form plateau-like areas, they are invariably peat-covered. We thus find thick deposits of peat, resting either upon bare rock or loose rubbly detritus, along the broad ridge extending from Creag Mhor, on the north side of the Strath of Orchy, to Beinn Donachan. To the east of Loch Awe, where the hills are of a more undulating character, and consist essentially of broad elongated ridges, there is much hill-peat covering all the more gentle slopes and plateau-like summits. It is essentially a heather-peat, and weathers on the summits into the characteristic peat-bogs, and is cut into small gullies and hollows by small streams formed by the heavy rains. This hill-peat is only used for fuel when it occurs within easy distance of a dwelling, though doubtless it would be more largely used if more easy of access and transport.

Throughout the area to the west of Loch Awe peat is everywhere found covering the flatter portions of the hill-tops, and occupying the hollows, and clinging to the gentler slopes. Its average thickness would probably be about three or four feet, but there is no doubt that on the hill-tops it frequently attains a much greater depth.

H. K.

*Oban and Kilmore District.*—In this region the largest areas of peat are to be found on the raised beach terraces between the head of Loch Feochan and Loch Nell, and in the upper part of the Lusragan valley on each side of Dig Bharrain. Considerable areas of peat occupy the hollows on the plateau of volcanic rocks between Oban and Loch Nell, and on the higher plateau to the south of Loch Nell and Glen Feochan.

B. N. P.

*Benderloch and Ardmucknish District.*—The 50-feet beach deposits are mostly hidden under widespread peat-mosses which cover a large part of the Ardmucknish peninsula. West of the escarpment of the Old Red volcanic rocks and underlying conglomerates, the volcanic plateau holds numerous small peat-mosses in its hollows.

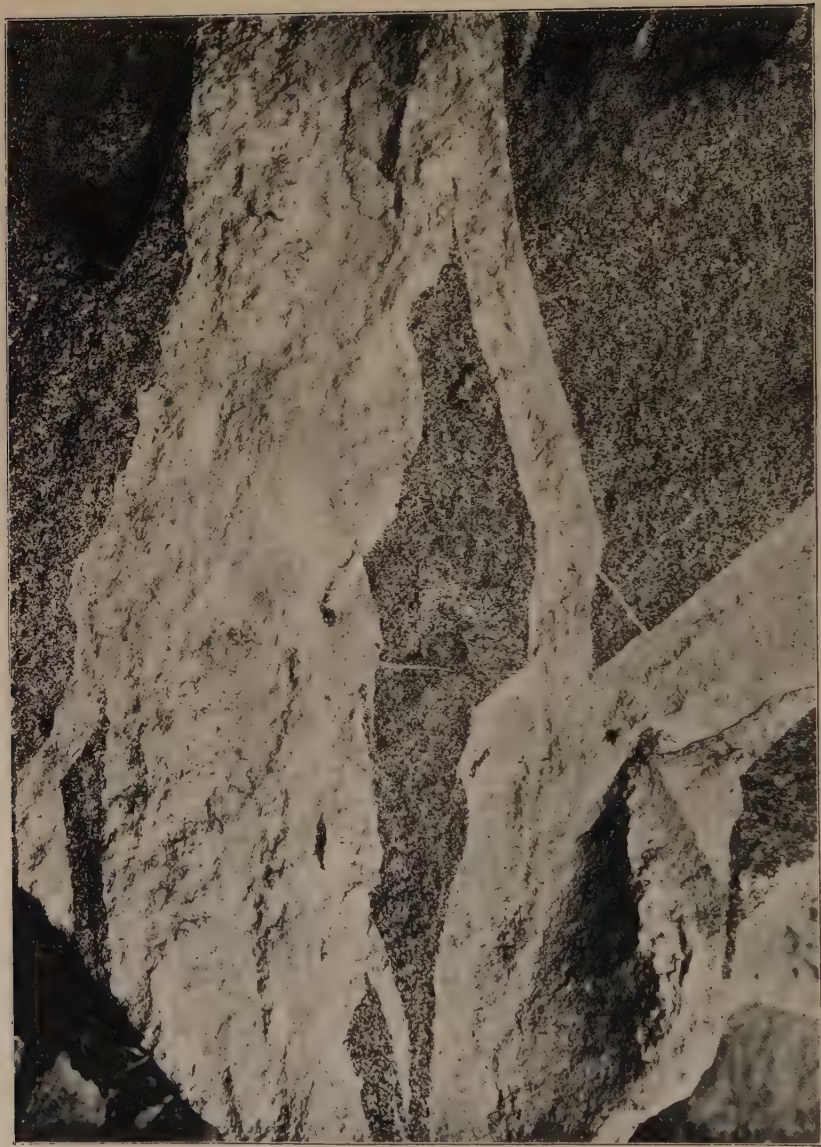
E. B. B.

*Loch Creran District.*—The deepest and best peat-mosses in the north-west corner of Benderloch lie around the Lochan Dubh, with an average depth of 20 feet. At Ardentiny oak stools are plentiful below the moss, while to the south of this there are several extensive peat flats. All the peat-mosses in this portion of Benderloch are situated upon the 50-feet beach, and are more or less locally used for fuel. In Strath Appin and along the west side of Loch Creran there are a few scattered mosses.

J. S. G. W.







Aplite Veins in Granite. Ben Cruachan Granite Quarries, 3 miles W.N.W. of Dalnally.

## CHAPTER XIV.

### ECONOMIC GEOLOGY.

*Building-stone, &c.*—The Ben Cruachan granite has for many years been quarried at Bonawe. The rock here is of the fine-grained Ben Cruachan type, and is of excellent quality for building purposes. Perhaps, however, the principal work carried on is that of making granite setts for road-paving, and these are shipped off to Glasgow and other places. A large quantity of the stone is also crushed by machinery, and three grades of the crushed material are turned out, the two finer grades being used in the manufacture of cement. There is no great extent, however, of the particular fine-grained type of stone which is found in these quarries; it extends merely for a short distance from the large quarry. Nearer the margin of the granite the rock would not be worth working owing to the presence of numerous inclusions of hornfelsed schist, and further into the mass the rock becomes coarse and of poorer quality.

At the Craig quarries, about two miles further up the loch, a coarser granite is quarried, which is of excellent quality for building purposes. It is the typical hornblende-biotite-granite of the Ben Cruachan mass. It can be extracted in large blocks, and is largely employed for harbour work on the Clyde, for ornamental purposes, and for building stone. There were formerly quarries at Craig Point, but these have for some time been abandoned on account of the large quantity of pink acid granite which occurs interbanded with the dioritic type, and which proves to be of too crumbling a nature to be of any commercial value. On the south shore of Loch Etive some quarries have recently been opened between Bonawe and Glennoe. The rock here resembles that of the Craig quarries, and is of good quality.

Near the head of Loch Awe, about three-quarters of a mile west of Castles, two large quarries have been worked in the Ben Cruachan granite for many years. More recently two more quarries have been opened in a fairly coarse quartz-diorite traversed by aplite veins. (Plate VII.) The stone is used for building and ornamental purposes, and recently has been employed by the Caledonian Railway Company in building the stone supports for the new bridge across Loch Etive, on the branch line to Ballachulish, at Connel Ferry.

In parts of the area where granite boulders are common, these have been largely used, when of good quality, for building purposes.

The dolerite of the east and west dykes is also an excellent building stone of very durable quality. It has been quarried at Inverlochy, near Dalmally, and several of the houses in that district are built of it.

The andesite of the Lorne plateau is usually a poor building stone, being so much split up by small joints. Occasionally, however, some of the more massive flows have been quarried successfully for building purposes. The red porphyrite, when not too far decomposed or shattered, is, however, a building-stone of very fair quality, and the quality is found to improve with the depth from the surface at which the rock can be quarried.

*Slate.*—The black slates were formerly quarried at Kilchrenan for roofing purposes, and slate pencils were also manufactured from them. Roofing slates were also manufactured from the black slates at Drumvargie, Oban. These quarries have, however, for some time been abandoned.

*Limestone.*—The largest area of limestone is to be found in Lismore. At Port Ramsay it is burnt in ordinary open draw-kilns, and produces a yellowish “thin” lime, in which the impurities are mainly sand derived from the quartz grains in the limestone. It is used chiefly for lime-manuring by the farmers of the neighbouring districts, and to a less extent as a building lime. The demand is insufficient to give constant employment throughout the whole year.

The limestone of the Kilchrenan area was also formerly burnt in many localities in that district.

*Road Metal.*—Road metal is everywhere easily procurable, and usually the local rock of any particular district is used for this purpose. The best quality of stone, however, is undoubtedly the granite of Ben Cruachan and the dolerite from the east and west intrusions and the Tertiary dykes. Porphyrite, andesite, epidiorite, limestone, and quartzite are also largely employed for many of the roads.

H. K.

*Pottery.*—The quartzite at Port Appin is quarried and conveyed to Glasgow, where it is ground down and used in the manufacture of “delft ware.”

J. S. G. W.

## APPENDIX.

---

### BIBLIOGRAPHICAL.

---

#### LIST OF WORKS REFERRING TO THE GEOLOGY OF THE DISTRICT INCLUDED IN SHEET 45.

1799. Saint-Fond, B. Faujas.—Travels in England and Scotland and the Hebrides. Translated from the French. London, 1799. Vol. I. (Bun-Awe), p. 305 and (Natural History of the Environs of Oban), p. 330. Vol. II. (The Isle of Kerrera), p. 144.
1800. Jameson, R.—Mineralogy of the Scottish Isles, Vol. I. (Seil, Easdale, and Oban), p. 192-199.
1810. Imrie, Lieut.-Col.—Some Remarks upon the Pudding or Conglomerate Rock which stretches along the whole of the South Front of the Grampian Mountains in Scotland, from where they commence in the West to where they finish their course towards the East in the German Ocean. *Mems. Wern. Soc.*, Vol. I., p. 453.
1814. MacCulloch.—Remarks on the Vitriified Forts of Scotland (Conglomerate of Lorne). *Trans. Geol. Soc.*, Vol. II., p. 264.
1817. MacCulloch, J.—Observations on the Mountain Cruachan in Argyllshire, with some remarks on the Surrounding Country. *Trans. Geol. Soc.*, Vol. IV., p. 117, and *Thomson's Annals of Phil.*, Vol. V., p. 151.
1821. Macknight, T.—Mineralogical Notices and Observations. *Mem. Wern. Soc.*, Vol. 3, p. 104.
1840. MacCulloch, J.—A Geological Map of Scotland, with Memoir on do. (published several years after MacCulloch's death).
1844. Nicol, J.—Guide to the Geology of Scotland. 8vo. Edin.
1851. Hopkins, W.—The Dispersion of Granite Blocks from Ben Cruachan. *Edin. New Phil. Jour.*, Vol. XLIX., p. 334, and Vol. LIII. (1852), p. 362. *Brit. Assoc. Rep.*, Vol. XX., p. 59.
1851. Hopkins, W.—On the Granitic Blocks of the South Highlands of Scotland. *Quart. Jour. Geol. Soc.*, Vol. VIII., p. 20.



1853. Argyll, Duke of.—Inveraray Granite District. *Quart. Jour. Geol. Soc.*, Vol. IX., pp. 134-360.
1855. Bedford, E. J.—Notice of some Raised Beaches in Argyllshire. *Quart. Jour. Geol. Soc.*, Vol. XI., p. 549, and Vol. XII. (1856), p. 167.
1859. Nicol, J.—On the Slate Rocks and Trap Veins of Easdale and Oban. *Quart. Jour. Geol. Soc.*, Vol. XV., p. 110.
1862. Murchison, Sir R., and A. Geikie.—First Sketch of a New Geological Map of Scotland, with Explanatory Notes.
1863. Nicol, J.—On the Geological Structure of the Southern Grampians. *Quart. Jour. Geol. Soc.*, Vol. XIX., p. 180.
1865. Geikie, (Sir) A.—The Scenery of Scotland viewed in connection with its Physical Geology, p. 174, etc.
1898. Argyll, Duke of.—On the Physical Geography of Argyllshire in connection with its Geological Structure. *Quart. Jour. Geol. Soc.*, Vol. XXIV., p. 255.
1871. Turner, (Sir) W.—On Human and Animal Bones and Flint from a Cave at Oban, Argyllshire. *Brit. Assoc. Rep.*, p. 160.
1874. Geikie, J.—The Great Ice Age (Loch Etive, from the Admiralty Chart), p. 300, etc.
1874. Judd, J. W.—The Secondary Rocks of Scotland. Second Paper on the Ancient Volcanoes of the Highlands. *Quart. Jour. Geol. Soc.*, Vol. XXX., p. 220.
1886. Bell, D.—Notes on the Geology of Oban. *Trans. Geol. Soc. Glasg.*, Vol. VIII., p. 116.
1888. Bell, W. H.—Geognosy of the Cruachan District. *Trans. Geol. Soc. Edin.*, Vol. V., p. 513.
1892. Dakyns, J. R., and J. J. H. Teall.—On the Plutonic Rocks of Garabal Hill and Meall Breac. *Quart. Jour. Geol. Soc.*, Vol. XLVIII., p. 104.
1892. Geikie, Sir A.—Geological Map of Scotland, reduced chiefly from the Ordinance and Geological Surveys, with Explanatory Notes. Edin., Bartholomew & Co.
1895. Argyll, Duke of.—Two Glens and the Agency of Glaciation. *Trans. Roy. Soc. Edin.*, Vol. XXXVIII., p. 193.
1895. Anderson, J.—Notice of a Cave recently discovered at Oban containing Human Remains, and a refuse-heap of Shells and Bones of Animals and Stone and Bone Implements. *Proc. Soc. Antiq. Scot.*, Vol. XXIX., p. 211.

1895. Turner, Sir W.—On Human and Animal Remains found in Caves at Oban, Argyllshire. *Proc. Soc. Antiq. Scot.*, Vol. XXIX., p. 410.
1897. Geikie, Sir A.—Ancient Volcanoes of Great Britain. Vol. I. (The Lake of Lorne), p. 341.
1897. Geikie, Sir A.—The Old Red Sandstone of Lorne. *Nature*, Vol. LVI., p. 157.
1898. Anderson, J.—Notes on the contents of a small Cave or Rock Shelter at Druinvargie, Oban. *Proc. Soc. Antiq. Scot.*, Vol. XXXII., p. 298.
1898. Traquair, R. H.—On a New Species of *Cephalaspis*, discovered by the Geological Survey of Scotland, in the Old Red Sandstone of Oban. *Trans. Roy. Soc. Edin.*, Vol. XXXIX., p. 591.
1898. Symes, R. G., and H. Kynaston.—Loch Awe Schistose Rocks, pp. 60-62. Fossils, 82-83. Volcanic Rocks, 84-85. Granitic and Volcanic Rocks of Ben Cruachan and Loch Etive, 85-93. Glaciation, p. 144. *Summary of Progress of the Geological Survey for the Year 1897*.
1899. Geikie, Sir A., R. G. Symes, and H. Kynaston.—Schists, pp. 38-39. Lower Old Red Sandstone Rocks and Fossils, pp. 71-75. Ben Cruachan and Glen Etive Granites and Contact Metamorphism, pp. 76-93. Carboniferous Rocks, pp. 76 and 129-130. Volcanic Vent near Loch Scamadale, pp. 153-155. Glacial Notes, pp. 169-170. *Ibid.* for 1898.
1899. Peach, B. N.—On some New Myriapods from the Palæozoic Rocks of Scotland. *Proc. Roy. Phys. Soc. Edin.*, Vol. XIV., p. 113.
1899. Hill, J. B.—On the Progressive Metamorphism of some Dalradian Sediments in the region of Loch Awe. *Quart. Journ. Geol. Soc.*, Vol. LV., p. 470.
1900. Peach, B. N., J. B. Hill, and H. Kynaston.—Schistose Rocks. pp. 42-47. Intrusive Rocks later than the Foliation, pp. 47-60. Glaciation, pp. 162-163. Old Red Sandstone Ostracoda, p. 186. *Summary of Progress of the Geological Survey for 1899*.
1900. Hill, J. B., and H. Kynaston.—On Kentallenite and its relation to other Ingeous Rocks in Argyllshire. *Quart. Journ. Geol. Soc.*, Vol. LVI., pp. 531-557.
1901. Hill, J. B.—On the Crush Conglomerates of Argyllshire. *Quart. Journ. Geol. Soc.*, Vol. LVIII., p. 313.

1901. Kynaston, H., and W. Pollard.—Loch Awe Boulder Bed, Schists, and Kentallenite, pp. 30-40. Analysis of Kentallenite, p. 160, Old Red Sandstone Lavas, pp. 71-73. Ben Cruachan Granite, pp. 73-75, *Summary of Progress of the Geological Survey for the Year 1900*.
1901. Kynaston, H.—On some Tuffs associated with the Andesitic Lavas of Lorne. *Trans. Edin. Geol. Soc.*, Vol. VIII., p. 87.
1901. Geikie, Sir A.—The Scenery of Scotland viewed in connection with its Physical Geology. 3rd edit. Loch Etive, p. 205. Loch Awe, pp. 154 and 260.
- 1901.—Heddle, M.F.—The Mineralogy of Scotland. 2 Vols. Edin.
- 1902.—Peach, B. N., H. Kynaston, and H. B. Muff.—Loch Awe District, pp. 123-126. Old Red Sandstone Volcanic Series, pp. 134-136. Unconformable Junction between Schists and Old Red Sandstone, p. 136. Lismore, pp. 140-141. *Summary of Progress of the Geological Survey for the Year 1901*.
- 1903.—Macnair, P.—The Building of the Grampians. *Proc. Roy. Philos. Soc. Glasgow*, Vol. XXXIV., p. 147.

# INDEX.

## A

ACHANAFÄUNDICH, 55.  
 Achavaich, 37, 72.  
 Achnacloich, 65, 66, 67, 75, 78, 166, 167.  
 Achnamady, 29, 30, 32, 45, 171.  
 Actinolite, 10, 11, 12, 14, 16, 17, 18, 50, 53, 54, 55, 56.  
 Acurragh, 27, 49.  
 Agate, 67.  
 Agglomerates, 6, 7, 8, 62, 67, 68, 69, 135.  
 Agriculture, 4.  
 Airds Bay, 164, 169.  
 Airds Park, 77, 78.  
 Airds Point, 64, 65, 78.  
 Albite, 11, 49, 50.  
 Albite schists, 6, 8, 11, 13, 47.  
 Allt an t-Sithein, 103, 104.  
 — Coire Creachan 96, 100.  
 — Coire Ghlas, 96, 97.  
 — Mhoile, 96, 99, 100.  
 — na Faing, 14, 15, 18.  
 — Odhar, 54.  
 Alluvium, 70, 169.  
 Amygdaloidal structures, 42, 43, 44, 64, 67.  
 Analcite, 125, 126, 127.  
 Analyses, chemical, 105, 126, 128, 129, 131, 146.  
 An Caorachan, 11, 12, 18.  
 Andalusite, 10, 11, 145.  
 Andesites, 64-69, 72, 74, 75, 77, 78, 99, 110, 151.  
 Anorthoclase, 127.  
 An Sithein, 152.  
 Aplites, 108.  
 Appin, 1, 4, 58.  
 Ardconnel, 72.  
 Ardentiny, 124, 125, 172.  
 Ardmutknish, 35, 124, 125, 126, 167, 168, 172.  
 — Bay, 36, 58, 59, 63.  
 Ardrishaig, 1.  
 — series, 6, 8, 17, 19, 20, 21, 22, 23, 27, 33, 35, 48, 49.  
 Ardtornish, 155.  
 Area and physical features, 5.  
 Aschen-structur, 79.  
 Ash-structure, 79, 80.  
*Asterocalamites scrobiculatus*, Schl., 155.  
 Augite-diorite, 120.  
 Awe River, 1, 3, 113, 167, 169.

## B

BAILEY, E. B., 110, 124.  
 Balinoe, 135, 137, 138.  
 Ballachulish, 34, 36, 91.  
 Ballimore, 42.  
 Barbreck, 43.  
 Barnacarry, 73.  
 Barriemore, 34, 169.  
 BARROW, G., 145.  
 Basalts, 7, 17, 20, 69, 75, 122, 123.  
 Basalt-jasper, 129.  
 Bealach nan Cabrach, 19, 23.  
 Beinn-a-Bhuiridh, 84, 85, 96, 99, 100, 122, 140, 143, 150, 157.  
 Beinn Bhalgairean, 2, 20, 158.  
 — Bhuidhe, 2, 16, 17, 19, 20, 23, 44, 48, 49, 57, 91, 95, 102, 103, 105, 116, 120, 152, 160, 162.  
 — Charn, 157, 162.  
 — Chas, 15, 18.  
 — Churalain, 33, 34.  
 — Donachain, 56, 172.  
 — Duirinnis, 84, 85, 112, 117, 148, 149.  
 — Eunaich, 82, 96.  
 — Ghlas, 2, 27, 28, 66, 67, 68, 77.  
 — Laoigh, 2, 16, 17, 19, 21, 22, 47, 49, 160.  
 — Lora, 62, 64, 65, 112, 171.  
 — Lurachan, 91.  
 — na Sroi, 39, 119, 122.  
 — Sguliaird, 2, 82, 84, 86.  
 — Starav, 3, 87, 88, 117, 160.  
 — Trilleachan, 87, 88, 157, 160.  
 Belnahua, 36.  
 Ben Bheula group, 10-12.  
 — Bhreac, 33, 156.  
 — Cruachan, 1, 2, 8, 82, 96, 157.  
 Benderloch, 2, 4, 35, 58, 62, 64, 65, 69, 78, 112, 124, 164, 167, 168, 171, 172.  
 Beregonium, 36, 58, 59.  
 Biotite schists, 40.  
 Black Lochs, 3, 167.  
 Blackmount, 1, 2, 3, 39, 51, 86, 87, 98, 114, 115, 151, 160.  
 Black schists, 2, 24, 25, 33, 37, 48, 143.  
 Bochyle, 55.  
 Bonawe, 1, 3, 4, 7, 62, 64, 82, 84, 112, 117, 139, 148, 149, 159, 164, 166.  
 Boulder bed, 6, 8, 26, 27, 28, 30, 31, 32, 59.  
 Boulder clay, 6, 161.



Bovuy, 42, 43.  
 Braglenmore Burn, 132, 134, 135.  
 Brannie Burn, 17, 103, 104, 152.  
 Breccias, 67, 75, 80, 81, 83.  
 Bridge of Awe, 6, 154, 156, 169.  
 BRÖGGER, Prof., 106.  
 Buchite, 129.  
 Building stone, 173.

## C

CALC-EPIDOTE-SCHIST, 52.  
 Calc-silicate hornfels, 30, 33, 48, 142, 153.  
 Camas an Fhàis, 35, 124, 125.  
 Camptonites, 124, 125, 129.  
 Carboniferous rocks, 154, 155.  
 Carn Gaibhre, 66, 67.  
 Castles, 173.  
 Catinnis, 91.  
 Ceann Garbh, 17, 18, 19, 23, 49, 118.  
*Cephalaspis lornensis*, Traquair, 69, 70, 72.  
 — *sp.*, 70.  
 Chert, 30.  
 Chloritic schists, 12, 14, 20, 41, 44.  
 Chromite, 105.  
 Cipolin, 142.  
 Cladich, 1, 27, 28, 42, 44.  
 — River, 3, 160, 162.  
 Clae's-gobhair, 82, 85, 88, 89, 114, 115, 162.  
 Cleavage planes, 22.  
 Clenamacrie, 74, 165.  
 CLOUGH, C. T., 123.  
 Coire Cruachan, 96, 99.  
 COLLINS, J. H., 90.  
 Colour banding, 22.  
 Conglomerates, 6, 62, 63, 66, 67, 69, 70, 72, 154.  
 Connel Ferry, 1, 3, 9, 38, 63, 64, 65, 72, 73, 160, 166, 168, 171.  
 Contact-metamorphism, 140-143.  
 — — by epidiorite, 28, 30, 45.  
 — — by kentallenite, 152.  
 — — by newer granites, etc., 11, 15, 21, 29, 32, 45, 48, 120, 139-153.  
 — — by Tertiary camptonites, 129.  
 — — of epidiorites, 150.  
 — — of lamprophyres, 152.  
 — — of Lorne andesites, 151.  
 — — of Sedimentary series, 140-152.  
 Cordierite, 130, 143, 146, 147.  
 Corryghoil, 55.  
 Corundum, 144.  
 Cowal, 10, 13, 16, 17, 22.

Craigentaggart, 73, 74, 167.  
 Craig Point, 85, 173.  
 Creag Mhor, 67, 172.  
 Creagan Ferry, 32, 167.  
 Cruach Ard-dhuine, 65, 66, 75, 78.  
 Crush conglomerates, 58-61.

## D

DAKYNS, J. R., 102.  
 Dalintart, 72.  
 Dalmally, 1, 3, 8, 19, 22, 24, 34, 44, 52, 53, 91, 117, 119, 121, 158, 161, 164, 165, 174.  
 Dalnacabeg, 72, 73.  
 Diabase, 42.  
 Dig Bharrain, 166, 170, 172.  
 Diorite, 7, 81, 85, 89, 90, 91, 95, 107, 109, 111, 116, 120.  
 DITTMAR, VON CARL, 14.  
 Dolerite, 7, 42, 44, 121-124, 129.  
 Dolomitic limestone, 33, 35.  
 — schist, 34.  
 Drumvargie, Oban, 174.  
 Dunstaffnage, 70, 168.  
 Dunstaffnage Castle, 166, 168.  
 Dykes and sills, associated with newer granite and lava flows, 111-121.  
 Dykes, composite, 89, 90, 112, 113, 123, 132, 134, 135.

## E

EAS AM DAMH, 133, 134.  
 Easdale, 36.  
 — slate group, 35, 36, 38.  
 Economics, 173, 174.  
 Eilean Dubh, 37, 121.  
 — Ramsay, 37, 121.  
 Epidiorites, 2, 7, 8, 17, 20, 23, 27, 28, 29, 30, 41, 45, 47, 57.  
 Epidosite, 141.  
 Epidotic schists, 12, 14, 20.  
 Eriska Island, 33, 34, 169.  
 Erratic blocks, 6, 160, 163.  
 Etive River, 170.  
 Euchar River, 73, 165.  
 — valley, 163, 170.

## F

FALLS OF CRUACHAN, 140, 156.  
 Faults, 3, 7, 12, 13, 15, 70, 75, 156, 157, 158.  
 Felsitic lavas, 66, 67, 68, 77, 78.  
 Fennacrochan, 37, 80, 107, 108, 109, 161.  
 Feochan Bheag, 72, 73, 74, 167.  
 Firth of Lorne, 62.

Fissure vents, Tertiary, 135, 137.

FLETT, Dr., 34, 58, 100, 107, 129, 134, 145.

Flow brecciation in lavas, 73.

— structure in lavas, 64, 66, 67, 73, 77, 78, 97.

Fluvio-glacial gravels, 165.

Fluxion-foliation, 100.

Folding and progressive regional metamorphism, 47-61.

Ford, 3.

Formations and rock groups, 6-9.

Fossils from Old Red Sandstone, 69-72.

— Carboniferous, 155.

— Raised Beach, 168.

Fraoch Eilean, 22.

Fyne River, 12, 15, 102.

## G

GARNETIFEROUS mica-schist group, 15-18.

— mica-schists, 6, 8, 14, 15, 16, 17, 18, 38, 39, 40, 47.

Garnets, 15, 16, 17, 18, 20, 44, 49, 50, 53, 54, 55, 56, 58.

GEIKIE, Sir A., 127.

Glacial deposits, 159-166.

Glen Aray, 160, 165.

— Creran, 1, 8, 33, 41, 116, 119, 120, 164, 169.

— Crutten, 37, 38, 70, 71, 72, 73, 75, 167, 168.

— Etive, 1, 159, 164, 169, 171.

Glenfeochan, 67, 76, 163.

Glen Fyne, 1, 2, 3, 4, 7, 8, 11, 12, 13, 14, 16, 17, 18, 19, 40, 48, 49, 95, 102, 111, 117, 158, 160, 162.

— Kinglass, 2, 82, 83, 85, 86, 87, 114, 120, 160, 162, 167, 169, 171.

— Liver, 167.

— Lochy, 1, 17, 19, 28, 39, 40, 51, 119, 121, 122, 160, 161, 162, 165.

— Lonan, 64, 65, 66, 67, 75, 77, 112, 163, 165, 166, 170.

— Nant, 4, 42, 65, 66, 76, 77, 116.

— Noe, 82, 84, 88, 157, 173.

— Orchy, 39, 44, 53, 54, 56, 58, 89, 90, 91, 119, 120, 122, 160, 161, 162, 164, 165, 171.

— Salach, 1, 3, 7, 33, 45, 62, 70, 156, 167.

— Shira, 2, 3, 4, 8, 19, 20, 23, 27, 44, 47, 48, 111, 116, 119, 122, 158, 160, 162.

— Strae, 1, 39, 56, 58, 82, 83, 89, 90, 112, 120, 156, 160, 162, 164, 165.

Gneissose grits, 10, 15.

Granite, 7, 8, 11, 20, 23.

Granite Beinn Bhuidhe, 102.

— Ben Cruachan, 7, 21, 29, 32, 45, 48, 82-91, 101, 102, 111, 112, 114, 117, 164, 173.

— — — basic and acid modifications, 84, 85.

— — — contact zone, 83, 96, 139.

— — — dykes cutting, 113.

— — — gneissic structure, 86.

— — — marginal differentiation, 95.

— biotite, 87.

— Blackmount type, 82-87, 88, 164.

— Glen Fyne, 11, 13, 48, 102, 116.

— hornblende-biotite, 84.

— inclusions in, 149.

— micro, 111.

— porphyritic, 86, 87.

Granitite hornblende, 85, 86.

Granulitic gneisses, 10, 15.

— schists of Moine type, 38-40.

Graphitic schist, 17, 28, 29, 36, 37, 53.

Gravels, 6, 165.

"Green Beds," 12, 14, 17, 47, 50.

Grits, 63.

## H

HARKER, A., 129, 131, 133.

Hayfield, 21.

HEDDLE, Dr., 127, 128.

HILL, J. B., 24, 47, 59, 89, 91, 98, 109, 177.

Hornblende andesites, 66, 68.

— lamprophyres, 89, 109.

— rock, 89.

— schist, 7, 8, 12, 14, 22, 40, 41-46, 50.

Hornfels, 8, 21, 23, 29, 30, 32, 33, 45, 48, 142, 143, 153.

## I

IGNEOUS rocks, 7, 8, 11, 41.

Inistrynich, 19, 23.

Intrusive rocks, 7, 8.

Inveraray, 1.

Inverawe, 22, 169.

Inverchorachan, 11, 12, 14, 15, 18, 102, 158.

Inverinan, 8.

Inverlochy, 53, 119.

Isoclinal folding, 29.

## J

JOINT-PLANES in granite, 88.

JUDD, Prof., 155.

## K

- Kampecaris forfarenensis*, 69, 72.  
 Kentallen, 91, 105.  
 Kentallenite, 7, 17, 20, 48, 89, 91-95, 103-107, 121, 152.  
 — Allt an t-Sithein and Brannie Burn, 103.  
 — Glen Orchy, 91-95.  
 — chemical comparisons, 105.  
 — composition, 105.  
 — contact alteration by, 152.  
 — distribution, 107.  
 — mineral associations of, 106.  
 — modifications of, 92, 93, 104, 107.  
 — petrological affinities of, 93, 95-104, 106, 121.  
 Kerrera, 63.  
 Kersantites, 119.  
 KIRSTON, R., 155.  
 Kilbride, 38, 67, 71, 72, 76, 77.  
 Kilchrenan, 1, 3, 4, 8, 29, 30, 31, 42, 43, 45, 48, 57, 76, 112, 115, 150, 161, 164, 171, 174.  
 Kilchrenan Burn, 4.  
 Kilmartin, 3, 59.  
 Kilmelfort, 1.  
 Kilmore, 1, 69, 72, 73, 137, 157, 161, 163, 165, 167, 168, 170, 172.  
 Kinglass River, 3, 170.  
 KYNASTON, H., 28, 65, 75, 89, 91, 109.

## L

- LACROIX, Prof., 142.  
 Lag na Liunge, 22.  
 Lairig Torran, 100, 157.  
 Lamprophyres, 7, 8, 17, 20, 89, 92, 109, 111, 116, 119, 120, 121, 152.  
 Landslips, 73, 74.  
 Lapilli, 65, 79, 80.  
 Larig, 55.  
 Lava flows, 62, 63, 72.  
 — brecciation of, 66, 67.  
 Lavas, acid, 62, 68, 77, 78.  
 — basic, 62, 64, 68.  
 — intermediate, 62, 68.  
 — vesicles in, 64, 67, 75, 77.  
 Ledaig, 63, 64, 167.  
 Lime, manufacture of, 174.  
 Limestone, 2, 6, 8, 13-15, 20, 21, 22, 23, 24, 25, 27, 28, 29, 33, 34, 37, 47, 69, 174.  
 Lismore, 1, 4, 8, 35, 37, 47, 58, 80, 107, 109, 121, 122, 123, 153, 161, 169, 174.  
 "Lit. par Lit." injection, 83, 142.  
 Loch Awe, 1, 2, 3, 4, 8, 19, 20, 21, 22, 23, 24, 27, 30, 41, 42, 43, 47, 48, 49, 51, 57, 59, 62, 68, 84, 85, 111, 116, 117, 139, 140, 143, 150, 156, 164, 171, 172, 173.

- Loch Awe grits and quartzite, 24, 25, 28-32.  
 — group, 23-37, 47, 48, 52.  
 — Craignish, 59.  
 — Creran, 1, 2, 4, 8, 32, 33, 34, 35, 45, 47, 62, 82, 83, 84, 156, 162, 163, 164, 167, 168, 172.  
 — Dochard, 39, 40, 82, 85, 86, 162, 171.  
 — Ericht, 157.  
 — Etive, 1, 2, 3, 4, 7, 62, 63, 65, 67, 70, 74, 82, 83, 84, 86, 111, 112, 139, 148, 150, 156, 157, 159, 160, 164, 166, 167, 168, 173.  
 — Feochan, 72, 122, 132, 134, 135, 164, 165, 167, 168, 172.  
 — Fyne, 12.  
 — Laidon, 157.  
 — Linnhe, 4.  
 — Melfort, 62.  
 — Nant, 4, 29, 65, 68, 69.  
 — Nell, 3, 71, 72, 73, 74, 163, 165, 166, 167, 170, 172.  
 — Scamadale, 1, 3, 8, 67, 68, 73, 74, 119, 122, 132, 133, 134, 135, 161, 164, 165, 170.  
 — Tromlee, 171.  
 — Tulla, 162.  
 Lochan Dubh, 36, 172.  
 — Dubha, 67, 68.  
 Lochy River, 3, 51, 53.  
 Lorne "traps," 62.  
 Lusragan Burn, 166, 167, 170, 172.

## M

- MAGNETITE VEINS, 92.  
 Malacolite-hornfels, 149.  
 Marble, 33, 45, 142, 153.  
 Meall an Laoigh, 89, 90, 91.  
 — Copagach, 91, 120.  
 — Cuanail, 96, 157.  
 — Garbh, 82, 83.  
 — nan Tigearn, 17, 19, 118, 158, 160.  
 — Reamhar, 17, 18.  
*Mesacanthus mitchelli*, 69.  
 Metamorphism, 10, 21, 22.  
 — regional, 47-58.  
 — contact. See Contact metamorphism.  
 Mica andesites, 66, 67, 68.  
 — schists, 15, 22, 40.  
 Michel Lévy, 83, 142.  
 Micro-granite, 111.  
 Minettes, 110, 119, 121.  
*Modiola macadamii*, Portl., 155.  
 Moine schists, 6, 8, 38.  
 Monadh Driseag, 85, 96, 140, 143.  
 Monchiquites, 124, 127.  
 Moor of Rannoch, 3, 157, 160.  
 Moraines, 6, 162.

Moss of Achnacree, 166, 167, 171.  
Mudstones, 62, 73.

## N

NA CAILLEACHAN, 56.  
Nant River, 167.  
New Inverawe, 29.  
Newer igneous rocks, 82-110.  
NEWTON, E. T., 167.  
North Shian, 169.

## O

OBAN, 1, 2, 4, 8, 37, 38, 58, 62, 63, 64,  
69, 70, 72, 73, 122, 137, 157, 160,  
161, 163, 164, 165, 166, 167, 168,  
170, 172, 174.  
Old Red Sandstone, 6, 7, 29, 62-81.  
Older igneous rocks, 41-46.  
Olivine monzonite, 91.  
Orchy River, 3, 19, 51, 52, 55, 170,  
171.  
Ostracods in Old Red Sandstone, 69.

## P

PASS OF BRANDER, 1, 3, 7, 8, 19, 21,  
29, 32, 42, 45, 47, 48, 51, 57, 62, 66,  
68, 69, 70, 82, 83, 84, 112, 113, 116,  
121, 139, 140, 143, 150, 151, 154,  
156, 169.  
PEACH, Dr. B. N., 155.  
Peat, 6, 9, 171.  
Pegmatite, 39.  
Pennyfuir, 72, 166.  
Phyllites, 2, 6, 8, 20, 22, 53.  
Picotite, 105.  
Picrite, 90, 92, 93, 94, 95.  
PIRSSON and WEED, Messrs., 106.  
Plant remains in Old Red Sandstone,  
69.  
POLLARD, Dr. W., 105, 128, 131.  
Population, 4, 6.  
Porphyrite, 2, 20, 45, 87, 96-101, 111-  
114.  
Port Appin, 33, 34, 169, 174.  
—— Ramsay, 169, 174.  
—— Sonachan, 31, 43, 44.  
Pottery, 174.  
Progressive metamorphism. *See* Meta-  
morphism, regional.  
*Pterygotus anglicus*, 69, 72.  
Pyrites, 36, 37, 52.  
—— magnetic, 53.

## Q

QUARRIES, 76, 85, 173.  
Quartzites, 2, 6, 8, 20, 21, 22, 23, 25,  
26, 27, 28, 32, 33, 34, 35, 36, 37, 38,  
39, 40.

Quartzose schists, 21, 22, 33, 38.  
Quartz-porphry, 7, 8, 87, 111, 112.  
—— segregations, 18, 23.

## R

RA CRAIG, 19, 24, 51.  
Raised beaches, 6, 9, 35 70, 166.  
Recent deposits, 6, 159.  
Regional metamorphism. *See* Meta-  
morphism.  
Rhyolites, 7, 132, 133.  
Rholitic felsites, 7.  
River erosion, 170.  
—— systems, 2.  
Road metal, 29, 174.  
*Roche moutonnées*, 159, 163.  
Roofing slate, 25, 29, 48.  
ROSEBUSCH and IDDIGS, 90.  
Ruadh Garbh, 34, 35, 169.

## S

SAILEAN SLIGENACH, 125, 126, 129.  
SALOMON, VON W., 146, 147.  
Sand dykes, 64, 73.  
Sands, 6.  
Sandstones, 6, 62, 63, 66, 68, 69, 70,  
73, 154.  
Sanidine, 78.  
Scamadale, 74.  
Scarba, 129.  
Scenery, 2, 9, 11, 18, 20, 41, 49, 51,  
62, 65, 86, 88, 122, 123, 156.  
Schiehallion, 8, 34.  
Selma, 36, 59, 70.  
Sericite schists, 20, 22.  
Shales, 6, 62, 63, 66, 68, 69, 70, 72,  
73, 74, 154.  
Shells from raised beach, 168.  
Shian Bay, 33, 34.  
Shira, 27.  
Sior Lochs, 65, 78.  
Slates, 22, 24, 25, 29, 35, 36, 48, 174.  
Socach, 17, 19, 22, 28, 52, 58.  
Soil, 4.  
Spessartites, 110, 119, 120, 121.  
Spherulitic structures, 66, 77, 78, 123,  
124.  
Spinelle, 145.  
Sron Mhor, 27.  
Sron na Craoibhe, 37, 108, 110, 121,  
123, 169.  
Stac a Chuirn, 20, 23, 102.  
Stob Ghabhair, 82, 85, 115.  
Strae River, 3, 157, 171.  
Strath of Orchy, 4, 8, 19, 28, 38, 44,  
47, 48, 51, 52, 53, 57, 111, 165, 170,  
172.  
Strathappin, 33, 34, 156, 169, 172.  
Syenite, 107, 108.  
SYMES, R. G., 63, 136, 137.



## T

TAILOR'S LEAP, 66, 77.  
 TAIT, D., 154.  
 Taycreggan, 43.  
 Taynuilt, 1, 4, 65, 66, 67, 75, 76, 77.  
     78, 112, 164, 166, 167.  
 TEALL, Dr. J. J. H., 85, 90, 102, 106,  
     113, 120, 140, 143, 150.  
 Teatle water, 3, 19, 20.  
 Tertiary dykes, 8, 38, 70, 122.  
 Tervin, 21, 22, 29.  
 Teschinites, 125, 129.  
*Thelodus* sp., 69.  
 Timber, 4.  
 Tom Bharra, 28.  
 Tonalite, 107, 108.  
 Torr-an-Tuirc, 73, 165.  
 Torr Dhamh, 71, 74.  
 Tourmaline, 13, 54.  
 Trachytes, 7, 132, 133.  
 TRAQUAIR, Dr., 70.  
 Tuffs, 7, 62, 64, 65, 66, 67, 68, 69, 78.  
     — acid, 65, 66, 68, 69, 78.

## U

UNCONFORMITY, 28, 30.  
 Upper Sonachan, 28, 31.  
 Uralite, 99.

## V

VARIOLITIC STRUCTURE, 124.  
 Veins, pegmatite, 11, 39, 56, 94.  
     — quartz, 11, 23, 39.  
 Vogesite, 90, 110, 119, 121.  
 VOGELSANG, CARL, 147.  
 Volcanic plateau, 2, 71, 74.  
     — rocks of Lower Old Red Sand-  
         stone, 62-81.  
     — vents, 7, 74, 135, 137, 138.

## W

WEED AND PIRSSON, MESSRS., 106.  
 WILLIAMS, G. H., 106.  
 WILLIAMS, GILBERT, 144.  
 WILSON, J. S. GRANT, 91, 119.





FIG. 1.

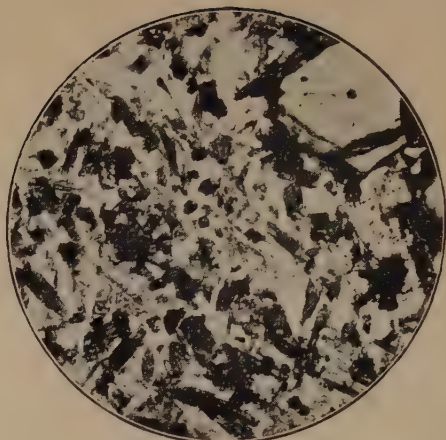


FIG. 2.

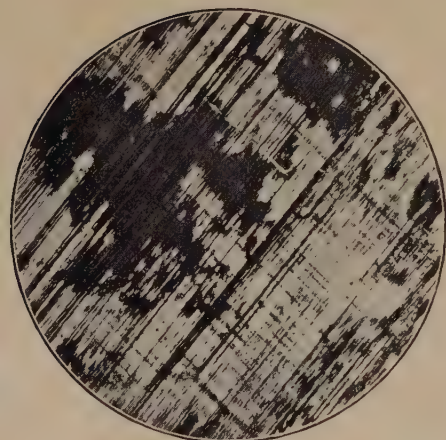


FIG. 3.

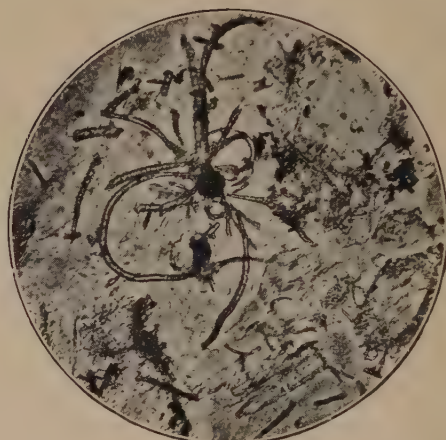


FIG. 4.

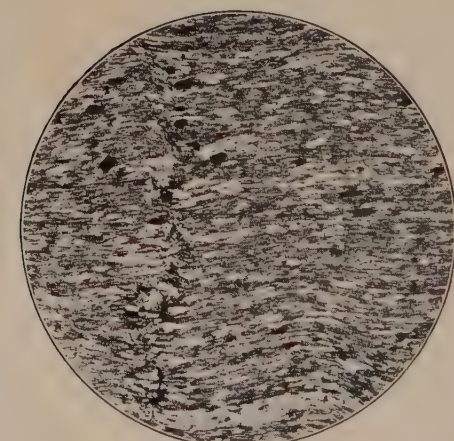


FIG. 5.

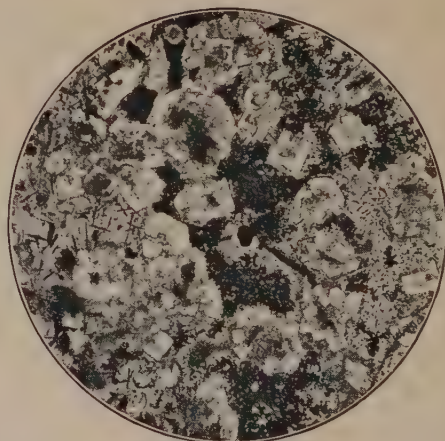


FIG. 6.

PHOTOMICROGRAPHS.

## DESCRIPTION OF PHOTOMICROGRAPHS.

### PLATE VIII.

- FIG. 1.—Variolite, north-east corner of Camas an Fhais, Ardmucknish [magnified 35 diameters, slide 10950 B]; showing the branching and plumose habit of the skeleton crystals of pyroxene in this rock. In other parts of the slide the feldspars form large, coarse, radiate spherulites.
- FIG. 2.—Camptonite, west shore of Fionn Aird, about  $\frac{1}{3}$ -mile north of Rudha Fionn Aird, Ardmucknish [magnified 60 diameters, slide 13197]. A large crystal of decomposed olivine is visible in one corner of the field. The rest is occupied by brown hornblende, purplish-brown augite, and plagioclase feldspar. The hornblende is rendered in dark shades, but shows its characteristic outlines in transverse sections.
- FIG. 3.—Anorthoclase or Soda Microcline, from monchiquite dyke, west shore of Camas an Fhais, Ardmucknish [magnified 25 diameters, slide 10946]. The cross-hatching is visible in the photograph (which was taken with crossed nicols) and also the variable double refraction in this mineral.
- FIG. 4.—Buchite or Vitriified Phyllite, north-east corner of Sailean Sligenach, Ardmucknish, Argyllshire [magnified 250 diameters, slide 11821]. Curved trichitic growths of green augite surround a small crystal of magnetite and lie in a matrix of clear brown glass.
- FIG. 5.—Phyllite, north-east corner of Sailean Sligenach, Ardmucknish [magnified 21 diameters, slide 11833]. This shows the unaltered rock at a distance of six feet from the margin of the dyke. It is well foliated and consists of chlorite, muscovite, quartz, and iron-oxides.
- FIG. 6.—Buchite or Vitriified Phyllite (in contact with camptonite dyke), same locality as above [magnified 37 diameters, ordinary light]. Crystals of cordierite, with glass enclosures, lie in a clear brown glassy matrix which is dusty-looking from the abundance of microliths of augite and grains of magnetite, etc. The cordierite prisms have hexagonal cross-sections. In polarised light they break up into sectors, showing that they consist of interpenetrating twins.













- Sheet 5. Ayrshire Coal-fields (east side).  
 „ 6. Renfrewshire, Dumbartonshire, Ayrshire.  
 „ 7. Cheviot and Lammermoor Hills.  
 „ 8. Clyde Coal-field and Campsie Hills.  
 „ 9. Ayrshire Coal-fields (Muirkirk and New Cumnock).

**IV.—Vertical Sections. 3s. 6d. per Sheet.**

- Sheet 1. Edinburgh and Haddington Coal-field.  
 „ 2. Fife Coal-fields.  
 „ 2A. Fife Coal-fields.  
 „ 3. Kilmarnock Coal-field.  
 „ 4. Clyde Basin Coal-field.  
 „ 5. Stirling and Clackmannan Coal-fields.  
 „ 6. Muirkirk, Lesmahagow, and Douglas Coal-fields.  
 „ 7. Lanarkshire Coal-fields (Rutherglen and Carluke).

**V.—Memoirs of the Geological Survey of Scotland.**

(1.) **GENERAL MEMOIR:—**

Silurian Rocks of Britain. Vol. I. Scotland. 15s.

(2.) **ECONOMIC MEMOIR:—**

The Oil-Shales of the Lothians. 4s.

(3.) **MUSEUM GUIDE:—**

Guide to the Collections of the Geological Survey. 2d.

(4.) **DISTRICT MEMOIRS:—**

- Cowal, Argyllshire. 6s.  
 East Lothian (out of print).  
 Central and Western Fife and Kinross. 5s. 6d.  
 Eastern Fife. 8s.  
 Skye. The Tertiary Igneous Rocks of. 9s.  
 Islay, &c. 2s. 6d.  
 The Geological Structure of the North-West Highlands of Scotland. 10s. 6d.

(5.) **SHEET MEMOIRS:—**

- Sheet 1. Wigtownshire, South-Western Districts. 3d.  
 „ 2. Wigtownshire, South-Eastern Districts. 3d.  
 „ 3. Wigtownshire, Western Districts. 3d.  
 „ 4. Wigtownshire, E. part; Kirkcudbrightshire, portion of S.W. Division. 9d.  
 „ 5. Kirkcudbrightshire, Southern Districts. 1s. 6d.  
 „ 7. Ayrshire, South-Western District. 3d.  
 „ 9. Kirkcudbrightshire, N.E.; Dumfriesshire S.W. 1s.  
 „ 13. Ayrshire, Turnberry Point. 3d.  
 „ 14. Ayrshire, Southern District. 3d.  
 „ 15. Dumfriesshire, N.W.; Ayrshire, S.E.; and Lanarkshire, S. 3d.  
 „ 21. Buteshire (Arran, Central, and N. and S. Bute), Argyllshire, Ayrshire (parts of). 4s.  
 „ 22. Ayrshire, Northern District, and parts of Renfrewshire and Lanarkshire. 3d.  
 „ 23. Lanarkshire, Central Districts. 1s.  
 „ 24. Peeblesshire, Lanarkshire, Edinburghshire, Selkirkshire (parts of). 3d.  
 „ 31. Lanarkshire, N.; Stirlingshire, S.; Linlithgowshire, W. 2s. 3d.  
 „ 32. Edinburghshire and Linlithgowshire. Out of print. New edition in preparation.  
 „ 34. Eastern Berwickshire. 2s.  
 „ 37. Mid-Argyll. 3s.  
 „ 45. Argyllshire, The Country near Oban and Dalmally. 2s. 6d.  
 „ 55. Perthshire, The Country round Blair-Atholl, Pitlochry, and Aberfeldy. 3s.  
 „ 60. The Small Isles of Inverness-shire. 4s. 6d.  
 „ 70. Inverness-shire. West-Central Skye, with Soay. 1s. 6d.  
 „ 75. Inverness-shire, Elginshire, Banffshire, Aberdeenshire (parts of). 1s.  
 „ 76. Aberdeenshire, Central. 1s.  
 „ 85. Elginshire, Banffshire, Aberdeenshire (parts of). 1s. 6d.  
 „ 87. Aberdeenshire and Banffshire (parts of). 9d.  
 „ 97. Northern Aberdeenshire. Eastern Banffshire. 4d.

*A detailed Catalogue may be had on application to Messrs. W. & A. K. JOHNSTON, Ltd.,  
 2 St. Andrew Square, Edinburgh.*